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EXPERIENCE IN THE METALLOGENIC REGIONAL ZONATION OF THE U.S.S.R.[1]

by

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This paper describes an outline of the metallogenic zonation of the U.S.S.R., on the principle of the separation of the distribution areas of Alpine, Mesozoic, Hercynian, Caledonian, and Proterozoic endogenetic ore deposits. The mineralization of the provinces of the Soviet Union is established as being polycyclic in character by the occurrence within the provinces of ore deposits of several metallogenic times. The associations between the mineralizations of the preceding and subsequent epochs and certain features of the general evolution of endogenetic mineralizations from the Archean to the Tertiary are discussed.

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GENERAL PRINCIPLES OF METALLOGENIC ZONATION

Inasmuch as the differentiation of the long process of mineralization in the interior of the earth is made on the basis of a concept of mineralization time divisions and their stages, a metallogenic zonation of a country into ore provinces can be accomplished by outlining the areas of development of the ore deposits belonging to the same time. In the U.S.S.R., there is evidence of a more or less intensive development of six metallogenic time divisions: the Alpine, Mesozoic, Hercynian, Caledonian, Proterozoic, and Archaean (possibly more than one Archaean).

It has been proposed [3] to separate three stages of the endogenetic mineralization within each time division, to correspond to the successive stages of the transformation of a geosyncline to a platform. The early prefolding stage resulted in the formation of ultrabasics, basics, their acid and alkaline differentiates and associated magmatic and skarn deposits of iron, titanium, chromium, platinum compounds, copper, and nickel. The middle, co-folding stage was the time of the main folding or immediately following this time, when the intrusion of granitoid batholiths took place, along with the formation of the associated skarns, pegmatites, greisens, and hydrothermal deposits of nonferrous, rare, and noble metals. The late post-folding stage is a transition to platform conditions, with the formation of minor intrusions and their paragenetic associates -- the hydrothermal deposits of nonferrous, rare, and radioactive metals.

It appears from the analysis of the mineralization of the U.S.S.R. provinces that there are practically no instances of commercial mineralization at all three stages, in any one of the provinces. There are provinces with well-developed mineralization during the early and the middle stages, but not at the late. The Urals are one of such provinces. On the other hand, provinces are known with well-defined deposits at the middle and late stage, and with little or no mineralization, at the late stage. The remaining provinces of the U.S.S.R. are of this type. Accordingly, all ore-bearing provinces, binary as they are, may be divided into two types: 1) provinces with a co-folding and a pre-folding mineralization; 2) provinces with a co-folding and a post-folding mineralization. It must be again emphasized that we are not concerned here with mineralization in general, but with a mineralization resulting in the formation of commercial deposits.

The areas of the development of rocks and associated ore deposits of the early and middle stages are recognizable in the ore provinces. The area of the development of the late stage ore deposits usually cover that of the middle stage. For this reason, an interior differentiation of the areas of the ore provinces belonging to a particular metallogenic time division, by their ore-bearing formations corresponding to several

[1] Opyt metallogenicheskogo rayonirovaniya teritorii SSSR.

development stages, is possible only for the provinces of type one, i.e., for the Urals. More important for the differentiation of the ore provinces, is a separation within them of segments synchronous in their history but having a different position in the geosynclinal structure. Here belong, first of all, the axial downwarps (troughs) of the geosynclines, and the subsequent central uplifts replacing them, on the one hand; and the peripheral parts of the geosynclines (shelves), on the other. The latter are intruded by moderately acid granitoids of the second stage, along with the formation of associated skarn and hydrothermal, chiefly sulfide, deposits. The central uplifts, in the meantime, are a site of acid and ultra-acid granitoid intrusions, accompanied by the formation of pegmatites, greisens, and quartz veins with specific, chiefly tin, tungsten, molybdenum, beryllium, and lithium, mineralization. Thus, belts of essentially different ore deposits can be formed in the framework of a single stage, but in different parts of the geosyncline. This phenomenon was noted in the description of the ore provinces of eastern Trans-Baikal and the Altai [5].

Generally speaking, it is not only the differentiation of the rock complexes which is paramount in the regionalization within the area of the ore provinces, for ore deposits of both the middle and the late stages, but also the isolation of zones of different mobility: 1) stable, 2) undergoing a protracted subsidence (depressions), and 3) characterized by stable uplifts. In this way, structural facies zones are designated, divided by faults which are deep-seated, in many places, and are of paramount importance for a metallogenic zonation within the ore provinces.

These principles of metallogenic differentiation can be applied in the making of mineralization maps for individual provinces. For a zonation of the entire territory of the U.S.S.R., it is expedient to separate first the distribution provinces for the ore deposits of a definite metallogenic time.

THE PRINCIPLES OF SEPARATION OF THE ORE PROVINCES OF THE U.S.S.R.

It appears to us that the separation of the ore provinces in the U.S.S.R. is best done by outlining the areas of development of the ore deposits for each time division.[2] However, the endogenetic mineralization of each succeeding time, being always epigenetic with relation to the mineralization of the preceding time, may be superimposed on the areas of development of the earlier-formed ore deposits, thus creating zones of development of deposits of different ages. It is, therefore, proper to designate the ore provinces on the basis of a separation of the distribution areas for ore deposits of the terminal mineralization time. In that case, they will include the distribution zones of both the preceding and the superimposed younger mineralization, which must be outlined separately. The distribution areas of the younger mineralization, superimposed on the segments of the ancient platforms, is best outlined separately. An outline of such a metallogenic zonation of the U.S.S.R., according to this principle, is presented in Figure 1.

With this approach, the provinces of an Alpine, Mesozoic, Hercynian, Caledonian, and Proterozoic mineralization can be outlined. It must be noted that the outlines of these provinces do not quite coincide with those of the folded zones which are represented according to their age, on the excellent tectonic map of the U.S.S.R., on a scale of 1:5,000,000, compiled under the direction of N.S. Shatskiy, A.A. Bogdanov, N.A. Belyayevskiy, M.V. Muratov, and others. This is because some of the important endogenetic ore deposits, located within large areas of a number of ore provinces, were formed in a post-folding time and even in a succeeding time (for instance, in central Kazakhstan, in the northern part of central Asia, in the Far Northeast, and in other places). For this reason, the tectonic map of the U.S.S.R. may be widely used in the metallogenic zonation of our country with but a few corrections.

Following the above criteria, the following provinces may be designated among the distribution areas of the endogenetic mineralization in the U.S.S.R.:

I. The Alpine: 1) the Far Northeast, 2) the Caucasus, 3) the Carpathians, 4) Kopet-Dag. The narrow zone of the Far East Alpine mineralization is best described in conjunction with the Mesozoic province of the Trans-Baikal-Maritime Oblast' (Province).

II. The Mesozoic: The Trans-Baikal-Maritime (Mongolian-Ohotsk belt and its maritime branches).

III. The Hercynian: 1) the Urals; 2) Kazakhstan; 3) Central Asia. Here belong also the Donbas, Novaya Zemlya, Yuzhnyy (South) Taimyr, and the Tom'-Kolyvan' zone.

IV. The Caledonian: the Altai-Sayan province, with the northern part of the Taimyr.

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[2] This does not exclude the possibility of making index maps of individual ore formations, deposits of individual metal ores or their groups, and the zonation on the principle of separation of different development types of geosynclines and platforms.

FIGURE 1. Map of the metallogenic zonation of the U.S.S.R.

Figures on map are ore provinces: Alpine: 1 -- Far Northeast; 2 -- Caucasus; 3 -- Carpathians; 4 -- Kopet Dag; 5 -- The Pamirs; Mesozoic (Kimmeridgian): 6 -- Trans-Baikal-Maritime; Hercynian: 7 -- Urals; 8 -- Kazakhstan; 9 -- Central Asia; 10 -- Donbas; 11 -- Taimyr; 12 -- Tom'-Kolyvansk zone; Caledonian: 13 -- Altai-Sayan zone; Proterozoic: 14 -- southern part of the Siberian platform; 15 -- Baltic shield; 16 -- Ukrainian shield.

V. The Proterozoic: 1) the southern part of the Siberian platform; 2) the Baltic shield; 3) the Ukrainian shield.

Areas of the exclusive distribution of the last metallogenic time deposits coincide with the rock complexes of the corresponding geologic cycle. However, where the folded province includes rocks of the preceding cycles of geologic development, this mineralization is superimposed on the distribution zones of more ancient ore deposits. Areas of a polycyclic mineralization originated under those conditions. In this country, all ore provinces which overlie the entire folded provinces or their major parts belong to the polycyclic. Counting only the decisive mineralization times, bi-cyclic and tri-cyclic times may be separated. Among the bi-cyclic ones are the Far Northeast (with the Mesozoic and Alpine deposits), Trans-Baikal-Maritime province (with Hercynian and Mesozoic ore deposits), Kazakhstan, Middle Asia and the Urals (with Caledonian and Hercynian ore deposits), the Altai-Sayan folded province (with Proterozoic and Caledonian ore deposits). Among the tri-cyclic provinces are the Caucasus (with Hercynian, Mesozoic, and Alpine ore deposits) and the ore provinces of the Russian and Siberian platforms. Sizable ore deposits of the Archaean, Proterozoic, and Hercynian are known from the Baltic shield; and the Archaean, Proterozoic, and Mesozoic -- from the Aldan shield in the southern Siberian platform.

The inclusion of minor mineralizations would increase the number of mineralization times for nearly all of the above provinces. For instance, there are small shows of a Caledonian mineralization in the Caucasus; of the Proterozoic in Kazakhstan, etc. However, they may be disregarded in the initial regional zonation of the U.S.S.R.

The relationship between the preceding folded complexes, the associated intrusives and ore deposits, and the geologic formation of the succeeding development cycle, varies from place to place.

First of all, a brand new, rejuvenated geosynclinal system may emerge from the tectonically dismembered fragments of the preceding cycle, such as the Mongolian-Okhotsk Mesozoic geosyncline at the site of the Hercynian folded province. Second, the geosynclinal conditions of a succeeding cycle may continue in the framework of an uncompleted folding of the preceding cycle, as for instance in the Zaisan Hercynian geosyncline in Eastern Kazakhstan. Third, the folded structures, intrusive complexes, and associated ore deposits of a preceding cycle may be caught in the tectonic deformations and intrusions of the following cycle, while maintaining a transitional or a platform regimen, such as the Verkhoyansk-Chukotsk folded province of the Far Northeast, in the Alpine cycle. The problem of the relationship between the preceding and succeeding foldings is a complex one, and we cannot here go into its details. What we want to emphasize is the normal coincidence of several cycles of geologic development in the framework of the ore provinces. We believe that a very important problem of the relationship between the succeeding and preceding mineralizations arises in this connection. We shall consider some of its aspects after a brief description of the principal ore provinces of the U.S.S.R.

THE PRINCIPAL ORE PROVINCES

The Alpine Provinces

The Far Northeast. The tectonic maps of the U.S.S.R. show the Verkhoyansk-Kolymsk Mesozoic and the Koryak-Kamchatka Alpine folded provinces. With reference to the formation time of its endogenetic ore deposits, the latter should be assigned to areas of the Alpine mineralization which overlies the Mesozoic mineralization in its western part. This province belongs to the bi-cyclic metallogenic group, inasmuch as the Mesozoic and Alpine ore deposits have been developed within it. The Mesozoic cycle is marked by the lack of early ore deposits and by their subsequent association with granite intrusions of the middle and later stages. Two intrusive complexes were formed at the middle stage, in the period of an Upper Jurassic folding: the so-called pre-batholith complex of minor intrusions, of a quartz-albite composition, and the batholith complex of the Kolyma type granite intrusions [4]. The famous gold mineralization of the northeast is associated with the former; and the no less famous tin and the associated tungsten, and partly molybdenum, arsenic, and lead-zinc mineralization with the latter. The Alpine cycle cannot be separated into the classic stages of the geosynclinal history; still, three intrusive stages of igneous rocks can be recognized within it: the Okhotsk type pre-Upper Cretaceous -- Paleocene alaskites of the Omsukchan complex; and the minor bodies of chiefly Miocene granodiorites [7]. Molybdenum deposits are associated with the first stage; tin, and also tungsten and polymetallic deposits are associated with the second; mercury deposits gravitate toward the third stage.

The definite regional zonation in the distribution of the above-named five intrusive complexes and associated ore deposits over the northeast is not obvious, because of their being either completely or partially covered. However, four zones can be separated throughout that region, by the predominance of

specific metals. The eastern Yana-Indigirka-Kolyma zone is characterized by the development of gold and tin mineralization. Mineralization of the extended northern zone is marked chiefly by sporadic occurrences of tin ores. A broad and long belt of sporadic molybdenum mineralization extends along the Okhotsk-Chaunskaya volcanic belt. A subprovince of mercury ores coincides with the Koryakskiy-Kamchatka folded province.

The Caucasus. Endogenetic ore deposits of Caledonian, Hercynian, Mesozoic, and Alpine times are known from the Greater and Little Caucasus [1, 14].

The Caledonian mineralization is present within the western part of the Front and Main Ranges of the Greater Caucasus, and also in the Little Caucasus. Copper pyrite deposits and minor shows of chromium and nickel ores are associated with the early basic igneous activity of the Caledonian cycle. The subsequent granite-gneisses are associated with isolated pegmatites and high-temperature quartz veins with cassiterite, molybdenite, scheelite, arsenopyrite, and gold.

Associated with the basic extrusives and intrusives of the Hercynian cycle again are copper pyrite deposits and shows of titanomagnetite, chromium, and nickel ores. Granites of the main phases of Hercynian folding are associated with minor pegmatites, greisens, and high-temperature quartz and quartz-tourmaline veins carrying cassiterite, scheelite, molybdenite, and arsenopyrite. Associated with the minor intrusions of granite-porphyries and keratophyres, which terminate this cycle, are the lead-zinc deposits of the western part of the Greater Caucasus northern slope.

The Mesozoic cycle of endogenetic development is widely represented. Associated with the Little and Trans-Caucasus Liassic and Bajocian keratophyres and spilites are pyrite deposits of Chiragidzor, Kedabek, Laura, etc. The formation of the peculiar copper deposits and ore shows, extended along the Greater Caucasus diabase dikes, also belongs to the same period. In addition, very poor shows of a titanium-magnetite and chromite mineralization are known from gabbros of the upper and lower Svanetian. The middle stage granite intrusions have determined the scheelite and molybdenite skarn mineralization in Tyrny-Auz. Finally, the terminal series of minor intrusions of granodiorites, keratophyres, and albitophyres includes the pre-Callovian polymetallic mineralization of the Sadon-Unal'skaya group; the Trans-Caucasian barites, and the Dambludian and Kafanian copper and polymetallic deposits.

The center of gravity of the Alpine cycle endogenetic mineralization was shifted toward the Little Caucasus, although Alpine ore deposits are known from the Greater Caucasus, as well. Certain iron and copper pyrite deposits of the Somkhite-Kafan zones (Shamlug, Madneuli, etc.) are associated with a volcanic formation of the initial stage of thus (Upper Cretaceous) cycle. The subsequent quartz diorites, granodiorites, and syenite-diorites of the pre-Cenomanian igneous series carry rare skarn deposits with ores of iron and cobalt, along with copper-molybdenum and molybdenum ore deposits of the Miskhano-Zangezurskaya zone. Hydrothermal deposits of lead and zinc, antimony and mercury, gold, arsenic (simple sulfides), and thallium are known from the Caucasus, in association with the latest Tertiary minor intrusions of granodiorites, dacites, albitophyres, and other rocks.

Regional patterns of endogenetic mineralization are observable in many regions of the Caucasus, and in the province as a whole. Their general features are as follows: Polymetallic ore deposits of various ages predominate on the northern and southern slope of the Greater Caucasus. Rare mineral deposits (molybdenum, tungsten, mercury, arsenic), also of different ages, are concentrated along its axial part. Copper and molybdenum formations of the Mesozoic and Alpine metallogenic times are developed in the Little Caucasus.

Mesozoic Provinces

The Trans-Baikal - Maritime Province. In its position, this province corresponds to the Mongolian-Okhotsk folded zone, with its southern Amur branch.

Three cycles are recognized in the history of the geologic formation and development of this province: the Hercynian, Mesozoic, and Alpine. The distribution area of the Hercynian complexes and associated ore deposits is located chiefly west of the central zone of the Sikhote-Alin' range, and is fully covered by the development of Mesozoic ore deposits, which extend somewhat farther east, to the maritime zone of the Sikhote-Alin'. In the central Sikhote-Alin' zone, and sporadically to the west of there, the distribution area of Mesozoic ore deposits, in its turn, is overlain by the province of Alpine ore deposits which stretch farther east to include the maritime Sikhote-Alin' zone, Sakhalin, and the Kurile chain. Despite the presence of three cycles of geologic development in its confines, this province is nevertheless bicyclic, since it is the locus of a coincidence of either Hercynian and Mesozoic cycles (in the west) or of the Mesozoic and Alpine (in the east).

No major ore deposits of an early Hercynian cycle have been found in this province. The middle stage, corresponding to the post-Lower Cretaceous folding, is associated with an intrusion of granodiorites and the subsequent granites, accompanied by skarns with magnetite and by hydrothermal deposits of tin, gold, molybdenum, tungsten, and fluorite.

The Mesozoic era also witnessed the formation of two granitoid intrusions, but they came about in the reverse order. Middle Kimmeridgian granites are in association with pegmatites, quartz-greisen and quartz formations with tin and tungsten. Upper Kimmeridgian moderately acid granitoids are associated with polymetallic, gold, molybdenum, and arsenic deposits.

The multiphase intrusion of Alpine diorites, granites, and granite porphyries was accompanied by the formation of hydrothermal deposits of polymetal, tin, gold, fluorite, and mercury ores.

In some parts of the province, the several ore deposits are distributed, at times, in strictly defined zones. Typical, in this respect, is the eastern trans-Baikal region, where three ore belts were already recognized by S.S. Smirnov [13]. Subsequent study has established that the central tungsten-tin mineralization belt is located on the central uplift of a Kimmeridgian geosyncline, whereas the gold and molybdenum, along with the lead-zinc and molybdenum ore deposit belt, is associated with the peripheral (shelf) parts of that geosyncline.

Hercynian Provinces

The Urals. The local Hercynian cycle of the geosynclinal development, which is the basis of its geologic structure and metallogeny, has been well studied, although the formation conditions for the several ancient complexes in the western and eastern anticlinoria, and in the polar Urals, have not been differentiated. It is known, however, that igneous type titanium-magnetite deposits are associated with ancient gabbro-diorites, whereas the hydrothermal deposits of molybdenum, along with pegmatites carrying inconspicuous accumulations of beryllium and cassiterite are associated with ancient granites.

According to V.M. Sergiyevskiy, the early stage is very typical for the Hercynian cycle in the Urals. Ultrabasic rocks of this stage carry the well-known igneous type deposits of chromites; the basic rocks contain titanium-magnetite ores; whereas plagioclase granites and plagioclase syenites are associated with skarn deposits of iron and copper ores. Iron and copper pyrite ore deposits are associated with the volcanic series of spilite-keratophyres and albitophyres.

The middle stage, corresponding to the main phases of Hercynian folding, has been intruded by granodiorites, diorites, and the later alaskites. The predominating granodiorites and moderately acid granites were accompanied by the formation of skarn deposits with magnetite and of hydrothermal gold ores. Locally, the alaskite granites correspond to pegmatites with precious stones and rare metals, and with hydrothermal tungsten ores.

The late development stage is damped in the Urals. It is perhaps manifested in the sporadic deposits of barite, fluorite, gold-antimony, and quartz-gold-mercury ores.

The sharp zonal tectonic structure of the Urals is accompanied by the no less sharp regional zonation in the distribution of the endogenetic deposits. The metamorphic rock zone is associated with igneous and metamorphic deposits of titanium, iron, and magnesite. Igneous deposits of chromites and titanium-garnet rocks is associated with the ultrabasic and basic belts. The volcanic Ural belt carries pyrite ores. The so-called "eastern slope granite development zone" contains a concentration of the associated deposits of iron, gold, precious stones, etc.

Kazakhstan presents a typical bi-cyclic province of the distribution of Caledonian and Hercynian endogenetic deposits [10].

The Caledonian development cycle, with its structures, extrusives, and ore deposits, shows itself chiefly in western Kazakhstan. It is possible that the gold-bearing pyrite deposits were formed at an early stage which was characterized by an accumulation of spilite-keratophyre sequences and associated co-magmatic basic and acid intrusions. The middle stage witnessed an intrusion of Silurian granodiorites and granites, and the formation of minor quartz-greisen ore shows with cassiterite, monazite, and scheelite. The late stage is marked by the formation of minor Silurian and Devonian intrusions and of quartz-gold deposits. Thus, gold deposits are typical for the Kazakhstan Caledonian metallogeny.

The Hercynian cycle of western and central Kazakhstan ran its course under conditions transitional from a geosyncline to a platform; and under geosynclinal conditions, in eastern Kazakhstan. Despite these radical geologic differences, synchronous and identical intrusions, with the accompanying mineralization, took place everywhere in Kazakhstan during that cycle. An intrusion of minor ultrabasic and basic massifs took place at the early stage. It resulted in the formation of local

accumulations of chromite which did not affect the metallogenic aspect of the province. Two consequent granitoid intrusions occurred at the middle stage. The early middle Carboniferous moderately acid granites are associated with inconspicuous skarn deposits of iron, copper, molybdenum, cobalt, and polymetallic ores. Pegmatites and quartz-greisen deposits of molybdenum, tungsten, and tin are associated with the late Hercynian light-colored granites. Minor intrusions of a quartz-albitophyre and granite-porphyry composition were formed at the late stage of the Hercynian cycle. They are correlative with the formation of major and diversified deposits of polymetallic and copper ores and of less significant quartz-gold deposits.

Regional zonation in the distribution of endogenetic deposits is lacking in the western and central parts of Kazakhstan, with the exception of the tendency of Caledonian gold deposits to gravitate toward the northern edge of central Kazakhstan. The local Hercynian deposits, responsible for the overall mineralization picture, do not exhibit a regular zonal distribution in the confines of this province, being associated with major intersecting faults. Conversely, the eastern part of Kazakhstan displays an amazingly regular regional zonation in the distribution of the endogenetic mineralization [8]. Here, the following seven ore belts are recognized in connection with the transition from one segment of the Zaisan folded zone to another [11]:

1) Gornyy Altai, with its tungsten-molybdenum ore deposits;

2) Rudnyy Altai, with a polymetallic mineralization;

3) the south Altai gold deposit belt;

4) the Kalba-Narym zone with the tin and tungsten ore deposits;

5) the second belt of the Kalba gold deposits;

6) the poorly mineralized Zharma zone;

7) the Chingiz zone with its tungsten-molybdenum deposits.

This regional zonation has been determined by a regular spatial distribution of extruded complexes with their associated ore deposits. The late Hercynian light-colored granites and their subordinate rare-metal mineralization are distributed in the area of the Zaisan geosyncline central uplift and the adjacent platform edges. On the other hand, the quartz-albitophyres and granite porphyries, with the accompanying polymetallic mineralization, were formed in the peripheral (shelf) part of the geosyncline.

Central Asia. This is a bi-cyclic province of Caledonian and Hercynian mineralization. Caledonian granitoids, developed in the northern Tien-Shan and known from central Tien-Shan, are associated with minor skarn deposits carrying magnetite and gold, also with pegmatites carrying tin and rare minerals, and with quartz-greisen ore shows containing molybdenite; and possibly with minor deposits of lead-zinc ores.

The Hercynian cycle is characterized by ore deposits of the middle and late stages. Only small ore shows of chromium, iron, nickel, and cobalt are associated with the small bodies of ultrabasic and basic rocks of the early stage. The middle stage witnessed an intrusion of predominately moderately acid granites, known from the northern Tien-Shan and developed in the central and southern Tien-Shan. They are accompanied by skarn deposits with scheelite, hydrothermal deposits of arsenopyrite, and possibly lead-zinc ores. The emplacement of a system of minor intrusions, complex in its composition, took place at the Late Permian stage. These minor intrusions conditioned the development of hydrothermal deposits of lead and zinc, copper, bismuth, and fluorite. The later deposits of antimony and mercury, outside the Tien-Shan ore complexes, have possibly been tormed in connection with a Mesozoic or an Alpline metallogenesis.

There is no distinct regional zonation in the distribution of endogenetic ore deposits throughout central Asia. This is because the great majority of ore deposits of that province are of the same type, connected with Hercynian extrusives more or less evenly eistributed throughout the area. There are a few distinctive features for the main Tien-Shan zones, as expressed in the development of the leading metals. For instance, lead-zinc deposits predominate in northern Tien-Shan, where they commonly are of a complex composition (with tin, arsenic, etc.). Hydrothermal and skarn lead-zinc deposits are especially well developed in central Tien-Shan, along with scheelite skarn deposits. An extended belt of antimony and mercury ores is known from southern Tien-Shan where it cuts obliquely a wide zone of tungsten, tin, and arsenic ores.

Caledonian Provinces

The Altai-Sayan province. This province belongs to a bi-cyclic area of development of the Proterozoic and especialy of the Caledonian metallogenic times.

Proterozoic deposits are located in the

comparatively small areas of eastern Sayan, Kuznetsk Alatau, Gornyy Altai, and Tannu-Ola. The inconspicuous ultrabasic and basic massifs, as well as lower Proterozoic plagioclase granite intrusions, were not accompanied by appreciable mineralization. Mica-bearing and rare-metal pegmatites are associated with upper Proterozoic light-colored granites.

Five intrusive complexes and associated ore deposits are recognized in the Caledonian cycle. Deposits of asbestos, talc, magnesite, and minor shows of chromite, titanium-magnetite, and nickel mineralization are associated with the serpentinized massifs of the Salair phase. The Taconian granodiorites are accompanied by gold deposits. An intrusion of Erian light-colored granites was accompanied by the formation of pegmatites, greisens, and quartz veins with wolframite, molybdenite, and beryllium. Pyrochlore carbonates and rare-metal zones of albitized syenites are associated with a specific complex of minor intrusions of alkali rocks. Finally, a Tel'bes phase group of rocks of a complex composition includes skarn deposits of iron ore.

Proterozoic Provinces

Provinces of this epoch belong to pre-Paleozoic platform segments of the U.S.S.R. They may be regarded as Proterozoic on the basis of their terminal cycle of the geologic and metallogenic development of the pre-platform period of their existence. During the platform period, these provinces were involved at times in later processes of mineralization, superimposed on the areas of development of the geosynclinal and semiplatform cycles. Although these processes were locally very important for the metallogeny of pre-Paleozoic platforms, such provinces are assigned to the Proterozoic, however, on the basis of the main premise of metallogenic zonation according to which they are designated by the last cycle of their geosynclinal development. So designated, the southern part of the Siberian platform and the Baltic shield, are instances of Proterozoic provinces.

The southern part of the Siberian platform has a two-stage geologic structure. The geologic structures and ore deposits of the lower stage have been determined by Archaean and Proterozoic development cycles.

Recrystallized and metamorphosed basic and acid rocks are known from the Archaean crystalline gneisses, schists, marbles, and quartzites. Their palingenetic origin has unfavorably affected the mineralization. Associated with them are common pegmatites, which are of little practical value.

The Proterozoic cycle is marked by an earlier intrusion of gabbro-norites and by a later, wider distributed, granitoid intrusion. No important ore deposits, associated with the basic intrusion, have been found, as yet. Various groups of ore deposits are associated with the Proterozoic granitoids, in various areas of distribution of the lower structural stage, in the southern part of the Siberian platform. Here belong the skarn deposits of iron and boron, mica-bearing pegmatites, hydrothermal deposits of gold and quartz crystals, and the ore shows of lead, zinc, copper, and molybdenum.

The later, Mesozoic igneous activity and mineralization, which occurred under platform conditions, developed along different lines in different regions of this province. The uplifted and exposed parts of the platform basement are characterized by the fracture intrusions of minor hypabyssal alkaline rocks of the upper Mesozoic (Aldan, Yenisei Range, etc.). Associated with them are hydrothermal auriferous quartz and rare-metal carbonatite deposits. Lower Mesozoic trap volcanism (Lena-Yenisei interfluve region) developed in areas of a buried platform basement, covered by a comparatively flat lower and upper Paleozoic rock sequence. It was accompanied by the formation of assorted ore deposits, among them the following: 1) igneous deposits of copper-nickel sulfide ores; 2) igneous deposits of diamonds; 3) skarn and hydrothermal deposits of iron; 4) hydrothermal deposits of Iceland spar; and 5) allegedly hydrothermal deposits of lead and zinc.

The Baltic shield. Endogenetic Archaean and Proterozoic deposits and a superposed Hercynian mineralization are known in the Kola Peninsula and in the Karelian S.S.R. They are associated with a post-Bothnian complex of microcline granitoids and are represented by ceramic pegmatites, pyrrhotite-pyrite fahlbands with cobalt and nickel minerals, and by minor hydrothermal quartz veins carrying molybdenite.

Proterozoic ore deposits are associated with ultrabasic, basic, and acid intrusions separating the large blocks of Archaean crystallines. Proterozoic ultrabasics and basics are associated with igneous deposits of copper-nickel and titanomagnetite sulfide ores. The acid rocks of the Proterozoic are associated with ceramic pegmatites carrying mica and rare metal minerals, tin-containing skarns, and hydrothermal pyrite deposits.

The alkaline intrusion of the Hercynian cycle proceeded by way of major tectonic seams between Archaean and Proterozoic blocks, forming northwest trending belts. They are the concentration sites of igneous deposits of apatites with nephelines of rare metals (tantalum, niobium), titanomagnetite

and magnetite, also of pegmatites carrying mica, rare-metal minerals, carbonatites, and hydrothermal manifestations of molybdenum, polymetals, and fluorite.

MAJOR TIMES OF ENDOGENETIC ORE FORMATION IN THE U.S.S.R.

The Archaean is represented by ore deposits of pre-Paleozoic platforms and isolated massifs of most ancient rocks known from the folded provinces of later development cycles. The most typical such areas are the Baltic and Ukrainian shields of the Russian platform, the Aldan shield, the Anabarsk massif, the Yenisey uplift, and the eastern part of the east Sayan Siberian platform.

The formation of Archaean igneous rocks was accomplished chiefly by palingenetic processes extremely unfavorable for ore making. Accordingly, the Archaean is characterized by metamorphic ore deposits of the ferruginous quartzite type. Of some importance among the igneous ore deposits are the ceramic and a few micaceous pegmatites.

The Proterozoic produced a much more diversified, although still small, amount of ore deposits. They are distributed, first of all, in the areas of development of Archaean complexes, superimposed on the latter; second, throughout the vast province of the Baikalian folded complexes, the Vitim and Stanovik; and third, over large areas of the Altai-Sayan folded province.

Identified everywhere for the Proterozoic, are the early groups of ultrabasic and basic rocks and later acid intrusives which are subdivided into a granodiorite phase and a subsequent phase of granites and alaskites. Minor intrusions of the culminating igneous stage have not been identified for the Proterozoic.

Most characteristic for this time are: 1) igneous ore deposits having originated in basic magmas, and represented by ilmenite-magnetite ores and also by copper-nickel sulfides; 2) mica-bearing pegmatites of acid magmas; 3) hydrothermal pyrite and gold deposits.

Predominant for the Proterozoic are ores of iron, titanium, nickel (in a few places with cobalt and platinum), copper, vanadium, and gold.

The Caledonian was the culminating time for the Altai-Sayan folded province, and the one preceding the Hercynian metallogeny in most of the Kazakhstan and the northern Tien Shan zones. Endogenetic ore deposits of this time are also known from massifs of ancient complexes of other Hercynian and younger folded provinces (Urals, Caucasus, Trans-Baikal-Primorskaya (Maritime) province).

Basic intrusions of an early stage are poorly developed in the Caledonian provinces. Instead, moderately acid granitoids, and acid granites immediately following them, are widespread. Minor intrusions of the terminal stages of the Caledonian cycle have been noted as hypabyssal plutonic bodies of eastern Sayan, where their formation date is not well fixed and may turn out to be considerably later. Most characteristic for the Caledonian are: 1) assorted hydrothermal gold deposits in quartz veins, pyrites, and skarns; and 2) skarn deposits of iron ores.

No igneous ore deposits of any importance have been recognized from the Caledonian.[3] The same is true for greisens and for a number of groups of hydrothermal ore deposits of nonferrous and rare minerals, with the possible exception of local deposits of quartz-molybdenum and certain other ores. Thus, the only essential ore deposits of that period are those of told, iron, and partially of molybdenum.

The Hercynian is marked by the extraordinary variety and wealth of its endogenetic ore deposits, in great contrast to the small mineralization development of the preceding periods. These ore deposits are distributed over the Urals, Kazakhstan, central Asia, southern Taimyr, Tol'-Kolyvan' zone, as well as in massifs of Paleozoic rocks throughout the Mesozoic folded provinces.

In accordance with the geologic features of individual provinces, the Hercynian is marked by early intrusions of ultrabasic and basic rocks of various thickness. Identified everywhere is a complex of granitoid rocks and an acid rocks complex following it. Distinct minor intrusions terminating the Hercynian cycle have been identified in many places.

Sizable igenous ore deposits of chromium, platinum, and titanomagnetites, related to ultrabasic and basic intrusions in the Urals, are known for the Hercynian. Characteristic are skarn ore deposits of iron, copper, tungsten, and polymetals associated with granitoids of an early phase of acid intrusions; also pegmatitic, quartz-greisen and quartz ore deposits of tin, tungsten, and molybdenum, associated with subsequent intrusions of granites and alaskites. Minor intrusions of the

[3]Except for the Kusinsk type titanomagnetite ore deposits of the Urals, which are possibly Caledonian.

terminal stage are associated everywhere with the formation of hydrothermal ores of polymetals and copper.

The Hercynian witnessed the formation of major ore deposits of nearly every metal, with iron, titanium, vanadium, chromium, polymetals, tungsten, molybdenum, tin, bismuth, cobalt, gold, platinum, tantalum, and niobium prominent among them.

Hercynian deposits of the platform stage of development, known from the Baltic shield, will be discussed below.

The Mesozoic is quite peculiar in the evolution of its igneous activity. It appears to be marked by a reverse sequence in the development of plutonic complexes and associated ore deposits. Minor intrusions took place at early stages (prebatholithic intrusions of Kolyma), followed by an intrusion of acid granitic rocks and then by moderately acid granitoids, especially conspicuous in eastern Trans-Baikal. Basic rocks are conspicuous by their absence in the Mesozoic. Ore deposits of this era are distributed within the Far Northeast, Caucasus, and Trans-Baikal-Maritimĕ Province. Most important among them are: 1) hydrothermal ore deposits associated with early minor intrusions and with the latest granitoids; 2) pegmatite, greisen, and quartz ores of tin and tungsten, associated with acid granite rocks; 3) hydrothermal and skarn ores of polymetals, copper, arsenic (arsenopyrite), molybdenum, tungsten, and barite, accompanying the granitoid intrusions.

Igneous ore deposits of industrial significance are, as yet, unknown in the Mesozoic. Its ore shows are represented by accumulations of metals characteristic of associations of moderately acid to acid intrusions. Prominent among them are ores of gold, polymetals, arsenic, molybdenum, tungsten, and tin.

The Alpine is characterized bẏ the ore deposits of the Far Northeast, eastern part of the Trans-Baikal-Maritime Province, Caucasus, Carpathians, and Kopet-Dag. It is not marked by a clean-cut and consistent evolution in the formation of extrusive rocks and associated endogenetic ore deposits. Local intrusive sequences of varied composition, peculiar to individual provinces, occur. Basic intrusions are noncharacteristic, in most instances, although present locally (the Sevan ultrabasics, Caucasus). Major acid intrusions are diversified, irregular, and commonly mingle with minor intrusions instead of culminating in them.

This Alpine is marked by assorted hydrothermal ore deposits, with skarn deposits of iron and polymetal ores. Igneous and greisen ore formations are atypical and very rare.

Better developed are ores of copper, polymetals, tungsten, molybdenum, tin, and mercury; there are important isolated occurrences of iron, antimony, arsenic, cobalt, and gold.

The platform endogenetic mineralizations found their expression in the pre-Paleozoic platforms in the Hercynian and Mesozoic. Igneous activity and mineralization in the platform period, regardless of the time of origin, are similar and fairly specialized. Two extrusive complexes have been formed under those conditions -- a basic and an acid -- both controlled by major faults. Associated with the basic rocks are igneous deposits of primarily copper-nickel sulfide ores, also diamond mines and skarn and hydrothermal iron ore deposits. Especially common associates of the alkali rock complex are the peculiar carbonatites and albitites with accumulations of minerals of tantalum, niobium, cerium, and hydrothermal gold deposits.

SOME GENERAL METALLOGENY PATTERNS IN THE U.S.S.R.

1. The Proterozoic, Caledonian, Hercynian, Mesozoic, and partly the Alpine development cycles are clearly divisible into five consecutive extrusive complexes and associated ore deposits. The geosynclinal stage produced -- on a different scale for different places -- the first ultrabasic and basic complex associated with igneous and skarn ore deposits. The main phases of folding are accompanied by the formation of the second complex of major massifs of moderately acid granitoids and associated skarn deposits and hydrothermal deposits, chiefly of molybdenum and gold. Following this complex -- in few places preceding it -- the third complex was formed, also consisting of major acid massifs accompanied by pegmatites, greisens, and quartz veins with tin, tungsten, molybdenum, beryllium, lithium, etc. The geosyncline-platform transition period was accompanied by the formation of the fourth intrusive complex, that of minor intrusions of a complicated composition, associated with assorted hydrothermal ore deposits. Finally, the platform period may have been the time of the fifth complex, that of minor hypabyssal intrusions, either acid or basic, commonly accompanied by explosive vents with which are associated the above-mentioned peculiar ore deposits.

2. Intrusions of the first ultrabasic and basic complex usually are controlled by major faults. Intrusions of the second granitoid complex occur, as a rule, in the peripheral

parts of geosynclines along their shelves. Rocks of the third acid granitoid complex usually occur in geosynclinal troughs, at the sites of future central uplifts. Minor intrusions of the transition stage again are distributed along the major, usually longitudinal, faults. Hypabyssal intrusions of the platform period are associated with local, commonly transversal faults. The stable tectonic control of the distribution of igneous complexes leads to a regular spatial distribution of definite groups of endogenetic ore deposits, in many places expressed in a regional metallogenic zonation.

3. The intensity of the manifestation of these five igneous complexes, and of the associated ore deposits, is different for different metallogenic times (Fig. 2).

The first ultrabasic to basic complex is fairly well expressed in the Proterozoic, then again in the Caledonian; it is most significant for the Hercynian, not everywhere to be sure, but chiefly in the Uralian geosyncline. Beginning with the Mesozoic, intrusions were sharply curtailed. The second granitoid complex is very consistent for the Proterozoic, Caledonian, Hercynian, Mesozoic, and partly the Alpine. The third complex is also well expressed in all of those times, except the Alpine. The fourth complex of minor intrusions has been well expressed only since the Hercynian, to attain its greatest intensity in the Alpine.

4. The inconsistency in the development of igneous complexes has brought about a corresponding inconsistent intensity of the formation of various genetic types of ore deposits. The formation of igneous ore deposits terminated with the Hercynian; none has been formed since. Pegmatite ore deposits include some of the most ancient. However, prior to the Hercynian, they consisted chiefly of ceramic and mica source materials; only from that time on, have they been associated with rare-metal ores. Likewise, the greisen ore deposits essentially belong to the Hercynian and Mesozoic.

Hydrothermal ore deposits are lacking in the Archaean, and very poorly developed in the Proterozoic and Caledonian. They blossom forth in the Hercynian and maintain their dominant position in the Mesozoic and Alpine. The most persistent are the skarn deposits, known from all times, from the Proterozoic on.

5. The above distribution of intrusive complexes and of the genetic types of igneous ore deposits is more or less in accordance with certain features of the chronological development of the metal ore deposits. In this respect, the Hercynian metallogeny has a place of its own, characterized by a wide development of the genetic groups of all metal ores. As such, it is critical in the history of endogenetic mineralization in the U.S.S.R.

With this in mind, the endogenetic metal ore deposits may be divided into six groups. The first group includes metals whose ores were formed continually from the Proterozoic to Alpine; such "through" deposits include those of molybdenum and gold. The second group contains metals whose commercial ore deposits are known chiefly from the Proterozoic to the Hercynian; here belong iron, titanium, and nickel ores. The third group comprises metals whose ores are concentrated chiefly among Hercynian formations, namely chromium and platinum. The fourth group takes in metal ores from the Hercynian and subsequent times, up to and including the Alpine: copper, polymetals, antimony, and tin.

Assigned to the fifth group are metal ore deposits characteristic of the Hercynian and Mesozoic, among them tungsten, tantalum, niobium and cerium; finally, the sixth group includes ore deposits particularly typical of the Alpine and characterized by the occurrence of mercury.

6. Considered in the context of this paper, all ore provinces of the Soviet Union are polycyclic; i.e., endogenetic ore deposits of two, three, and more cycles are known from each.

In addition, the provinces of the second type, the most numerous in this country, are marked by an increased intensity of post-igneous mineralization toward the end of the development cycle, both in the framework of each cycle and going from earlier cycles to later ones. There is also a parallel decrease in the volume of igneous activity. Thus, a rule can be stated, according to which the geologic development of geosynclines, and their change to folded provinces, are accompanied by a decrease in the intensity of intrusive activity, whereas the intensity of postigneous mineralization increases, at times abruptly.

7. There also is a progressively increasing diversification in mineralization in every cycle, from the early to intermediate to late stages. During the early stage of a cycle occur similar chromite and titanomagnetite ore deposits under geosynclinal conditions; or else of copper-nickel sulfide ores under platform conditions. Associated with the middle stage is the formation of skarn, pegmatite, and greisen ore deposits, chiefly of tungsten, molybdenum, and tin, more or less similar to each other. However, they begin to show differences in individual provinces,

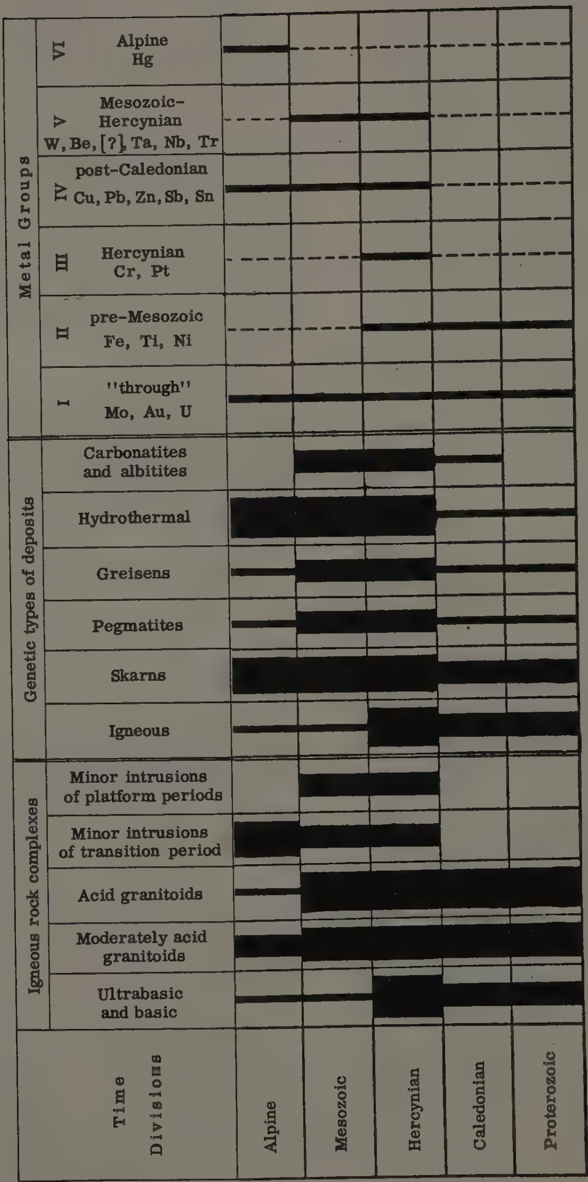

FIGURE 2. Intensity of the development of igneous rock complexes and of genetic types of endogenetic ore deposits for individual metal groups and for different metallogenic times. (Compiled by V.I. Smirnov.)

usually because of the preponderance of one mineral. Most diversified are ore deposits of the late stage. It is they that determine, most commonly, the specific metallogenic aspect of a province.

8. All ore provinces of this country are characterized by the presence of diversified ore deposits of particular metals, which constitutes the metallogenic aspect of each province. Those metals which are the most widely developed and fairly well concentrated in a given province, may be called typomorphic to it. As yet, we do not know the causes of this metallogenic specialization of individual provinces but, it must be taken into account.

Some geologists, students of endogenetic ore deposits in various regions of this country, have noticed the recurrence of the same metal ores, especially the typomorphic ones, from the most ancient to the youngest mineralization times. This was noticed, for instance, by D.I. Shcherbakov [15], for the Caucasus; by N.A. Belyayevskiy [2], for the Far East; by Ye.D. Karpova [6], for central Asia. A study of material on the metallogeny of the U.S.S.R. reveals that this pattern in the inherited development of typomorphic metal ore deposits is even more widespread and general. It is especially well expressed in areas of young mineralization, of the Mesozoic and Alpine, superimposed on the older areas of ore distribution. For instance, typomorphic for the Caucasus are ores of copper, molybdenum, and partly of polymetals. Also present are copper ores of the Caledonian (Urup), Hercynian (Kyzyl-Kol), Mesozoic (Alaverdy, Zangezur), and Alpine (Kadzharan, Agarak). Molybdenum ore deposits also are associated with the Caledonian (Blyb'), Hercynian (Belyagidon, etc.), Mesozoic (Tyrny-Auz), and Alpine (Paragachay) times. Occurring in the Caucasus are Hercynian lead-zinc ore deposits (Elbrus, Tyzyl) and similar younger Mesozoic and Cenozoic formations (Sadonian group), as well as the Trans-Caucasian Tertiary.

Tin ore deposits are among the typomorphics of the Trans-Baikal-Maritime metallogenic province, pre-Paleozoic, perhaps lower Paleozoic in part. Hercynian tin ore deposits have been found in the haloes of the Voznesensk granites. Mesozoic (eastern Trans-Baikal region) and Alpine (Mikoyanovskoye, Solnechnoye, the Sikhote-Alin' group) tin ore deposits are among those that are widespread.

Gold and tin deposits are among the typomorphics of the Far Northeast. The bulk of gold deposits of that province is associated with the Upper Jurassic complex of minor intrusions. Although no such large ore deposits have been formed in the later time, some gold deposits are known among those associated with light-colored granites of the Kolyma Upper Jurassic, with Cretaceous granodiorites of the Okhotsk complex, and with young Alpine granites of the Omsukchan complex. Well known for the same province are the two major times of a thick tin mineralization: the Upper Jurassic greisen-cassiterite and the Cretaceous to Tertiary, represented by ore deposits of the silicate-cassiterite formation.

Such an inherited nature of ore deposits also finds its confirmation in more ancient metallogenic provinces. An instance is the Urals, where the most characteristic typomorphics are iron ores. Iron concentrations literally permeate all of the Uralian mineralization processes. Major pre-Paleozoic (most likely Proterozoic) deposits of ilmenite-magnetite are known from there (Kusinsk, etc.). At early stages of the Hercynian cycle, iron was bound in chromites from ultrabasics (Don, Saranovskoye, etc.) and in titanomagnetites of the Kachkanar and other basic intrusions. Later on, in association with Upper Silurian to Lower Devonian plagioclase granites and plagioclase syenite intrusions, skarn deposits with magnetite ore were formed (Vysokaya, Blagodat' Mountains, etc.). Still later on, as late as the terminal stage of the Hercynian cycle, the second group of the most important magnetite-carrying skarn deposits (Magnitnaya, Kustanayskaya groups) was formed on the eastern slope of the Urals in association with an intrusion of granodiorites and granites. It is remarkable that such a saturation of endogenetic mineralization with iron, in the Urals, coincides with an abundance of sedimentary ore deposits of this metal, known literally from every segment of its composite stratigraphic section -- from the most ancient pre-Paleozoic complexes to and including the Paleogene.

It has been determined that in the recurrence of the geologic conditions of mineralization in a province, not only the ore occurrences of the typomorphic metals are repeated, but their types as well. The instances of that are the unusually similar Proterozoic and Hercynian titanomagnetite ore deposits of the Urals; Caledonian, Hercynian, and Mesozoic copper pyrite ores of the Caucasus; Paleozoic and Mesozoic and Cenozoic polymetal vein deposits of the same province; the deposits of vein-inclusion copper-molybdenum Caledonian (Boshchekul') and Hercynian (Kounrad) ores of Kazakhstan, etc. These instances suggest the inheritance, not only of the metal composition, but of the type of the typomorphic deposit. A change in the geologic conditions brings forth different types of these deposits, which is quite a common occurrence. For instance, among molybdenum ore deposits of the Caucasus, there are

quartz veins carrying molybdenite, hydrothermally altered minor intrusions of acid rocks with accumulations of the same mineral, vein inclusions of a copper-molybdenum formation, and molybdenum-carrying skarns.

The recurrence of the metal composition in endogenetic ore deposits cannot be regarded as a result of redeposition of the ore substance from ancient deposits, in the process of formation of the subsequent younger ore deposits. This would be in contradiction to the magnitude of the earlier, usually less extensive deposits, and to that of the younger and larger ones. Furthermore, a study of the isotope composition for the component elements in the ore minerals, such as lead, of different metallogenies, precludes such a borrowing and redeposition of the ore substance [12]. Such a redeposition, determined by a capture of the ore substance of ancient deposits and by its regeneration in the mineralization during the following times, can take place only in isolated instances.

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SOME PROBLEMS OF MAGMATIC MINERALIZATION[1]

by

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This paper deals, on the basis of modern physical and chemical concepts and experimental and geologic data, with the internal structure of magmatic melts, with the form of the occurrence of chemical elements in them, and with the mechanism of the differentiation of ore substance and of metals from the magma.

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PHENOMENA TAKING PLACE IN A MAGMATIC MELT

Despite the extreme diversity of opinion on the subject of the source of magmatic substance in endogenetic ore deposits, the vast majority of students maintain a concept of this source as a magmatic hearth, and correctly so. This view ties the origin of both magmatic ore deposits proper and the so-called postmagmatic ores, to intrusive activity and to various intrusive formations.

The geologic observations on the Uralian igneous ore deposits, together with special experiments and with physical and chemical patterns noted in metallurgic processes, all lead to certain conclusions on the problem of igneous mineralization and on some factors which regulate it.

The complex process of the formation of an ore deposit located away from the source medium can be divided into three stages: 1) phenomena taking place in the magmatic melt; 2) phenomena in the overlying rocks, caused by the movement of the separated ore-forming fluid; and 3) phenomena in the ore-deposition site.

This paper deals with the first group of these phenomena. It is an attempt to determine the way in which a magmatic mineralization is affected by factors previously taken into little or no account, and to derive, more or less hypothetically, the resulting patterns of deposition.

The Form of Occurrence of the Chemical Elements in the Melt

A magmatic melt, or magma, is a liquid with all the properties of matter in this state. In the character of their atomic bond, reflected in the sharp difference in physical properties, all liquids are divided into three extreme types [24]: the molecular, the ionic, and the electronic. The molecular liquids consist of simple molecules, such as benzene; or the associated, such as water or silica melt. They are extremely poor conductors of electricity. The ionic liquids, formed by mobile ions, are characterized by a high ionic conductance. They represent the so-called electrolytic conductors (of the second class). Typical of such ionic liquids are melts of such salts as the haloids of alkali metals. The electronic fluids include molten metals, certain sulfides, etc. Because of their structure -- a combination of positive ions and "electron gas" -- such liquids are good electronic conductors.

These three types of liquids are ideal and seldom occur in their pure state. Actual liquids always contain elements of different types, one usually predominating.

A magma is essentially a silicate melt. At the present time, the ionic theory of the structure of molten silicate systems has been universally accepted. As stated by O. K. Botvinkin [4, p. 210], "silicate melts, with their high mobility, belong to the group of ion-conducting liquids . . . The preponderance of ionic structure in these melts may be regarded as firmly established." Molten silicates are regarded as electrolytes [10, 11]. They should have the ionic structure of

[1] Nekotoryye voprosy magmatogennogo rudoobrazovaniya.

solid silicates, inasmuch as the elements in the ionically bound compounds are always present there as ions, regardless of the state of these compounds [19].

The ionic nature of a magmatic melt proper, too, is no longer in doubt. As early as 1933, C.N. Fenner [32, p. 75] voiced an assumption that "magmatic ingredients are undoubtedly ionized in part, and we can regard magma as an electrolyte." T. Barth [1] dwelt on this subject in more detail, in his belief that the degree of ion dissociation in melts is comparable with that in an aqueous solution of strong electrolytes. V.V. Shcherbina [38], in her special study of the occurrence of chemical elements in magmatic melts, cites a number of additional arguments in favor of such an assumption.

With its ionic structure, a magmatic melt carries such typical cations as Na^{+1}, K^{+1}, Ca^{+2}, Mg^{+2}, Fe^{+2}, and others, all very mobile and not occupying a definite position. Anions are chiefly represented by silicon-oxygen tetrahedrons which form one-two- and three- dimensional bonds, similar to those of crystalline silicates but more irregular. The presence of aluminum, titanium, and some other elements leads to the formation of more complex anions, of types $[AlSi_3O_8]^{-1}$, $[AlSiO_4]^{-1}$, $TiSi_4O_{12}]^{-4}$ or others [38]. In the field of synthetic silicate melts, O.A. Yesin and B.M. Lepinskikh [13], for instance, have experimentally confirmed, with the method of electromotive forces, the presence in a liquid metallurgic slag of silicon-oxygen anions $[SiO_4]^{-4}$, $[SiO_3]^{-2}_n$, $[Si_2O_5]^{-2}_n$, aluminum-oxygen anion $[Al_3O_7]^{-5}$, aluminum-silicon-oxygen anion $[Al_2SiO_7]^{-4}$, and titanium-oxygen anions $[TiO_4]^{-4}$ and $[TiO_3]^{-2}_n$. However, such a simple differentiation of a melt into cations and anions, cannot reflect its complex internal structure. At the present time, it can be accepted only as a first approximation.

There are several theories of the internal structure of liquids [4]. One of them is the quasi-crystalline state hypothesis, according to which the liquid structure presents a partly organized system of ions, intermediate between gases and crystals, but closer to the latter. Another hypothesis, the molecular one, now practically abandoned, holds that ions in a liquid emerge only as a result of electrolytic dissociation. Finally, A. Frenkel' advanced the theory of a discontinuous structure of liquids, wherein a liquid consists of a dynamically continually emerging and breaking-up group of particles and has interruptions in its continuity.

At the present time, more and more students hold to a more complicated theory of clusters of cybotaxes, which explains many of the physical and chemical properties of liquids and the patterns in their change depending on composition and temperature. According to this theory, as successfully applied by O.A. Yesin [10, 11, 12] to silicate melts, the organized structure of a liquid is not limited to volumes immediately adjacent to a particle but extends considerably farther away. More or less complex groups, the cybotaxes, appear and disappear in the liquid. The internal structure of cybotactic groups approaches that of a crystalline body, whereas the outer layers are less organized [4]. Thus liquids in general and various melts in particular, in breaking up into cybotactic groups, are characterized by a certain microheterogeneity, a very important factor in the geologic processes under consideration.

As a rule, the basis of a cybotactic group is represented by ions and their combinations, with various complications and enlargements in the change in the composition of the melt or in its temperature. O.A. Yesin [11] recognizes two extreme cases of ion groupings in a melt. In the first instance, the difference in the interaction energy of ions is so small, that the distribution of particles with one sign about the particles with another sign is of a purely statistical character. A theory for these, the so-called "perfect solutions", has been provided by M. Temkin [30]. In the other and opposite instance, the interaction energy of some of the ion pairs considerably exceed that of all others. Such particles will most commonly be found near each other, thereby forcing the other, weaker ions to form groups of their own. The homogeneity of the melt will then be disturbed by the formation of groups with different composition. The melt will become microheterogeneous, with a "continuous passage from one melt group to another possible only if there is a sufficiently large number of particles in each of them. This uneven distribution can attain such a degree that the microheterogeneity may become a microstratification" [11, p. 561]. O.A. Yesin proposed to separate the electrolytes of this type into a special class, because their distinct heterogeneity determines many aspects of their behavior and properties. Molten silicates are excellent representatives of just that class of microheterogeneous electrolytes.

O.A. Yesin [11, 12] has systematized those patterns which illustrate the distinctive microheterogeneity of silicate melts and refer in particular to their stratification (liquation), surface tension, the activity of oxides, electric conductance, and viscosity and its relationship to temperature. Experimental data characterizing these properties

confirm the possibility of microheterogeneity in melts. They render very probable the structure model of these melts, as proposed by O. A. Yesin.

In accordance with the theory of a cybotactic group, for example, molten magnesium orthosilicate, cannot be regarded as fully dissociated in the following simple way:

$$Mg_2SiO_4 \rightleftharpoons 2\,Mg^{+2} + SiO_4^{-4}.$$

MgO, with its ionic lattice, is fully dissociated in the melt:

$$MgO \rightarrow Mg^{+2} + O^{-2}.$$

However, an oxygen anion is only partially bound to complex SiO_2 compounds; it does not fully break them down to the simplest SiO_4^{-4} but rather produces a number of mobile equilibria, such as:

$$Si_2O_7^{-6} + O^{-2} \rightleftharpoons 2SiO_4^{-4},$$
$$3\,Si_2O_7^{-6} + 3O^{-2} \rightleftharpoons 2\,Si_3O_9^{-6},$$
$$(SiO_3^{-2})_{2n} + nO^{2} \rightleftharpoons nSi_2O_7^{-6},$$
$$nSiO_2 + nO^{-2} \rightleftharpoons (SiO_3^{-2})_n,$$
$$2nSiO_2 + nO^{-2} \rightleftharpoons (Si_2O_5^{-2})_n$$

and others, with considerably more complex formations [10]. As a result, one type of cybotactic group is represented by a collection of silicon-oxygen anions of $Si_xO_y^{-z}$, whereas the remaining O^{-2} ions are left surrounding Mg^{+2}, thus producing in the melt, cybotactic groups and segments similar in composition to MgO. A similar picture is observed in other molten silicates. Obviously, the stronger the cation and its interaction with O^{-2}, the fewer of the latter are bound with SiO_2. The interaction energy of Me^{+2} with O^{-2} increases inversely to the first approximation of the cation radius. For this reason, in melts of complex composition, strong cations are located chiefly in segments rich in O^{-2} anions, whereas the weak ones are grouped chiefly about $Si_xO_y^{-z}$ ions [11].

If the internal structure of a magmatic melt be considered with regard to its microheterogeneity, the first logical conclusion would be to assume a natural tendency of the magma toward stratification (liquation) and specifically toward the separation of the ore substance. This assumption of the separation of ore substance from a magmatic silicate melt, in a liquid state, is even more plausible considering the possibility of a nonionic occurrence of metals in the melt.

A magmatic melt is a liquid of a very complex composition. As such, it carries, along with the predominant ions, particles of other types characteristic of molecular and electron liquids. Specifically, the first type may include molecules of gases dissolved in the melt. The existence of the second type is suggested by both geologic and experimental data. According to the investigations by Ya. I. Ol'shanskiy [24, 25, 26], iron sulfide, for instance, is soluble to a considerable extent in silicate melts and in a number of liquids such as Fe, FeS, FeO, and FeO + SiO_2. A gradual solution achieves a gradual change from pure molten iron, a typically electron liquid, to a pure silicate melt of ferrous oxide, a typical ionic liquid. This change is effected by way of intermediate melts of iron sulfide and ferric oxide. The resulting continuous series of liquid mixtures of FeS + FeO presents an example of the so-called ion-electron liquids, i. e., liquids containing iron in atomic state, along with Fe^{+2} and O^{-2} ions.

In considering the nature of ferrous iron silicate melts and of FeS solutions in them, and accepting the concept of their microheterogeneity, Ya. I. Ol'shanskiy [25] assumed that the FeO rich cybotactic segments are formed with the participation of metal bonds. These are the segments of electronic conductance experimentally established for such melts. Particles of iron sulfide, dissolving in the silicate melt, enter these FeO-rich segments, because they are by now ion-electronic and are closer to the molten FeS, in their chemical nature, than the remaining portion of the silicate melt. In other words, the iron sulfide is distributed throughout the silicate melt not evenly, but is grouped rather in definite segments. In so doing, it intensifies the heterogeneity of the melt and is readily separated by stratification under proper conditions.

The possibility of iron and other metals occurring in atomic form, while in solution in silicate melts, has been confirmed by the interesting data of P. M. Shurygin [sic] and O. A. Yesin [37] on the solubility of iron in liquid slags. These authors have established that a drop of gold in a FeO - Fe_2O_3 - SiO_2 melt is considerably enriched in iron. A similar transfer of iron takes place from molten Fe_2SiO_4 to liquid copper. There is no sign of the dissociation of FeO into Fe_3O_4 and Fe. Different slags were used in the experiments. Besides iron and silica, they contained calcium oxide (as much as 30%), magnesium oxide (as much as 2.3%), and alumina (as much as 18%). The amount of recovered dissolved iron was different for different slags, fluctuating from a trace to 8.5%.

The authors concluded that iron and liquid slag form a true solution, similar to the long since known phenomenon of "metal mist" in molten salts, whose nature, according to ultramicroscopic study and to measurements of the electromotive force, leaves no doubts. The following homogeneous equilibrium takes

place in ferruginous slags:

$$2Fe^{+3}_{slag} + Fe_{slag} = 3\ Fe^{+2}_{slag}$$

This equilibrium is a result of a continuous electron exchange between atomic iron and Fe^{+3} and also among Fe^{+2} cations. It has not been discovered earlier probably because, in the presence of metal iron, it changes to the well-known heterogeneous equilibrium:

$$2Fe^{+3}_{slag} + Fe_{met} = 3Fe^{+2}_{slag}.$$

It is characteristic that in these experiments, gold too, in its atomic state, dissolved in the slags.

Considering the results of the experiments by O. A. Yesin, Ya. I. Ol'shanskiy, and others, it is reasonable to assume that magmatic melts can contain a definite amount of iron and other metals in atomic state or else as sulfides dissolved in it, in the manner of the "metal mist" in molten salts, thus intensifying its microheterogeneity by the presence of these particles in the composition of ion-electron cybotactic groups. Such a state of metallogenic elements in the magmatic melts may be an attribute of the latter, since its origin; however, it also may emerge in connection with a change in the external conditions or in the composition of the melt.

If what we have said is true, the change in the external conditions and in the composition of the melt may lead to a most important phenomenon, that of a sharp lowering of the solubility of metals in their sulfides, in a silicate melt, and to a stratification of the latter. We shall consider this phenomenon in detail, below. Here we only point, as a corollary, to the concept of microheterogeneity of magmatic melt, to the latter's inherent tendency to liquation and to a differentiation into two ionic liquids, as a result of the segregation of cybotactic groups of different composition, on one hand; and into an ionic (silicate melt) and an electron (ore substances) liquid, on the other.

Thus, the acceptance of modern ideas on the nature of silicate melts, leads to a concept of several forms of the occurrence of chemical elements in magma: 1) "free" readily mobile cations; 3) complex anions forming chiefly a silicon-oxygen network of various degrees of intricacy; 3) atoms of dissolved metals; 4) sulfides of the FeS type or the Fe_3O_4 type compounds, possessing metal bonds and representing electron liquids;[2] and 5) molecules (dissolved gases).

Segregation of Ore Substance from the Melt

As has been pointed out above, a magma may be conceived as a microheterogeneous ion-electron liquid, whose liquation takes place unavoidably with corresponding changes in the conditions, specifically with a change in the composition or temperature of the melt. The liquation of silicate melts, with the formation of two immiscible liquids is a natural extreme manifestation of microheterogeneity. The differentiation mechanism appears to be as follows [11]. In a MeO-SiO_2 system, for instance, the solution of MeO in SiO_2, is accompanied by a partial passage of oxygen ions from the metal oxide to silica, with a resulting combination of the type $Si_xO_y^{-z}$ silicon-oxygen anions. The greater the interaction of Me^{+2} with O^{-2}, the smaller is the latter's part to be bound to SiO_2. The remaining O^{-2} coninue to surround Me_2^{+}, creating cybotactic segments in the melt similar to MeO in their composition. Silica which has received an insufficient number of O^{-2}, forms large polyatomic anions, i. e., cation-poor cybotactic groups approaching those for pure liquid SiO_2. The melt becomes microheterogeneous; with a lowering of the MeO percent content, it differentiates.

Such a differentiation takes place with chemical elements present in the melt as ions. Elements which are present in the melt as atoms or sulfides, can be segregated in a separate phase, simply by virtue of their lowered resistance, which might be brought about by a lowering in the temperature and pressure during the injection of magma in the upper part of the earth's crust. Such a simple mechanism, however, cannot be universal; otherwise every intrusion would have been accompanied by ore bodies. The segregation of ore substance from the silicate melt is the result also of other factors.

One of the most important causes of the segregation of ore substance from a magmatic melt is a change in the composition of the melt as a result of its interaction with the enclosing rocks, first of all with limestones and then with other calcium-rich rocks. In particular, the relationship between the formation of iron ore contact-metasomatic deposits with the assimilation of limestones by granitoid magma is confirmed by numerous geologic data, and the concept of such assimilation is actively supported by many students. A. N. Zavaritskiy [14], who regards the liquation following the melting of limestones as a cause of the formation of a number of ore deposits, went so far, as early as in his 1926 classification, as separating a special type of synthetically liquated ore deposits. Subsequently, in connection with magnetite deposits associated with syenites,

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[2]Solid magnetite is an electron conductor. It seems to be logical that molten Fe_3O_4, too, should possess a considerable electron conductance [26].

he pointed out that the causes of the segregation of "ore magma" from a silicate melt should be looked for in the reaction between volatile compounds dissolved in a silicate melt, and the limestones [15, p. 72].

A. Ye. Fersman [33] explained the accumulation of large amounts of iron in the granite-limestone contact by the assimilation of the limestones by a granite magma and by the effect of CaO in these limestones, which dissolves in the magma. K. A. Vlasov [7], after A. Ye. Fersman, also connecting the formation of iron ore contact-metasomatic deposits with the assimilation of limestones by granite magma, stated that "iron, being a weaker base, is displaced by calcium oxide and does not enter the minerals of the magmatic stage of crystallization."

As shown by thermodynamic computations, the probability of the reaction of displacement of iron by calcium is very great. The theoretical feasibility of the process is determined by the sign of the change in thermodynamic potential ΔZ. If, under given conditions, $\Delta Z < 0$, the reaction is possible. Because of the lack of data for an exact computation of ΔZ, the trend of the reaction is usually judged by the sign and magnitude of thermal effect ΔH [18]. For reaction

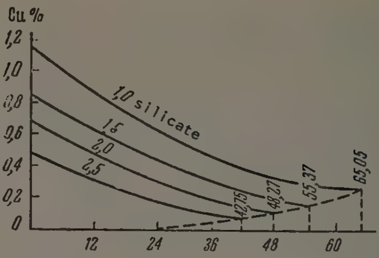
$$2\ CaCO_3 + Fe_2SiO_4 \quad Ca_2SiO_4 + 2\ FeO + 2\ CO_2 - 22.6\ \text{kcal/mol},$$

the thermal effect, at standard temperature, will be -22.6 kcal/mol. For reaction

$$CaCO_3 + Fe_2SiO_3 \quad CaSiO_3 + FeO + CO_2 - 17.2\ \text{kcal/mol}$$

it also is considerable, amounting to -17.2 kcal/mol. The displacement reaction of iron by calcium from silicates, indeed is very advantageous, thermodynamically, and will proceed very vigorously in both instances. This circumstance is also utilized in industry. Thus, limestone is added as flux in pyrite fusing, because "CaO, being a stronger base than FeO, is united first with SiO_2. Free FeO, in the presence of air oxygen, changes to Fe_2O_3 more intensively. Thus, for a constant amount of SiO_2 and air, the addition of lime brings about an intensive formation of magnetite." [35, p. 730].

Calcium also plays a positive part in the separation of copper. For instance, $CaCO^3$ is added in copper fusing, to reduce the copper content in the waste slag. The limestone depresses the solubility of copper sulfides in these slags by raising their CaO content [35]. Such an effect of CaO on the solubility of a copper matte with 30% Cu_2O was observed by V. A. Vanyukov, as early as 1916 (Fig. 1).



Note: Comma represents decimal point.

FIGURE 1. Copper concentration in slag melts as a function of the calcium oxide content. After V.A. Vanyukov [25] [sic].

Special experiments also bear testimony to the great part played by calcium in the separation of ore substance from the silicate melt. Thus Ya. I. Ol'shanskiy [25, 26] established experimentally that a partial replacement of FeO by CaO in various silicate melts leads to a sharp drop in the solubility of FeS in them (Fig. 2) and to the appearance of as much as 5% metal iron in the sulfide FeO phase; i.e., to the differentiation of the ore substance and to its liquation.

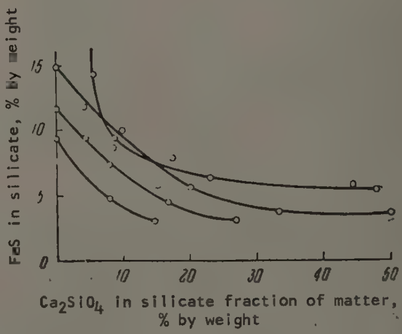


FIGURE 2. Concentration of FeS in silicate melts as a function of Ca_2SiO_4 content. After Ya. I. Ol'shanskiy [25].

According to Ya. I. Ol'shanskiy, the addition of CaO to a silicate melt promotes a decrease in the volume of ion-electron segments, where FeS is concentrated, because the presence of Ca^{+2} raises the

amount of iron leaving these segments. This is what brings about the solubility decrease in FeS. In other words, a melt, because of its microhomogeneity, has a tendency toward differentiation; this differentiation is aided by the addition of calcium. The same is true for the segregation of ore substance as oxide compounds: strong Fe^{+2} cations form cybotactic segments rich in O^{-2}, whereas SiO_4^{-4} [11] are grouped about weak Ca^{+2} cations.

Our own experimental study, as well as the earlier experiments of J. Stansfield [42], have shown an amazingly consistent differentiation of iron and other metals from melts of granite and other rocks when the latter are fused with limestones.

The Loss of Metals in Magma

An ore substance can take two courses after its separation from the silicate melt: it can either form isolated ore accumulations within it or leave the melt altogether, to form ore bodies outside the source medium.

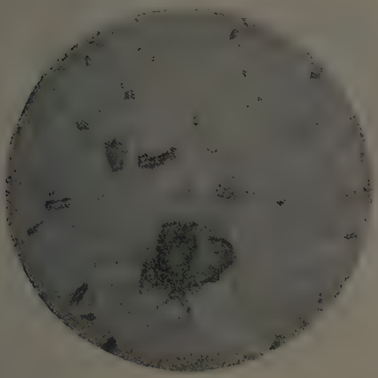


FIGURE 3. Dispersed droplets of metal iron (white). Reflected light; magnification X 290.

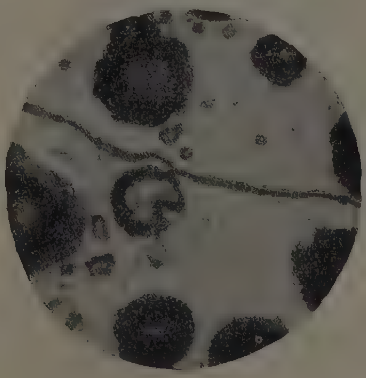


FIGURE 4. Segregations of metal iron (white) about gas bubbles. Reflected light; magnification X 63.

For the reasons already set forth, the segregation of the ore substance is expressed at the outset in a considerable enlargement of the cybotaxes, leading to the emergence of a dispersion of very fine droplets of ore liquid. These ore droplets are immediately enlarged, further coalescing among themselves chiefly with the help of gas bubbles, whose generation, either because of the pressure drop or in connection with the dissociation of limestones, takes place simultaneously with the liquation of the ore liquid. Subsequently, the very same gas bubbles transport the ore droplets to the upper parts of the melt, and beyond it. A further coalescence takes place in the process.

We were successful in observing this process in all its stages, in our experiments in the fusing and crystallization of a mixture of silicate rocks with limestones [23]. An idea of its mechanism can be obtained from photomicrographs Figs. 3-9. They reflect the initial formation of minute individual isolated droplets (Fig. 3), followed by a weak concentration of ore substance in similar isolated minute accumulations about gas bubbles (Fig. 4), and by the formation of an almost continuous fringe of such accumulations (Fig. 5) with a subsequent penetration of that fringe into the bubbles (Fig. 6). Within a bubble the ore substance now assumes an enlarged drop form (Fig. 7) and is carried upward by the bubble, where it can be observed, upon hardening, in spherical globules (Fig. 8). These metal iron globules, attaining 2 mm in diameter in our experiments, are located mostly above the crystallized melt surface; i.e., they are carried out completely, at times becoming partly imbedded in the solidified melt, under their own weight (Fig. 9). The globules can even get above the surface of the melt by climbing the crucible walls.

According to our experiments, other metals behave similarly to iron. Specifically, the surfaced iron globules contain relatively

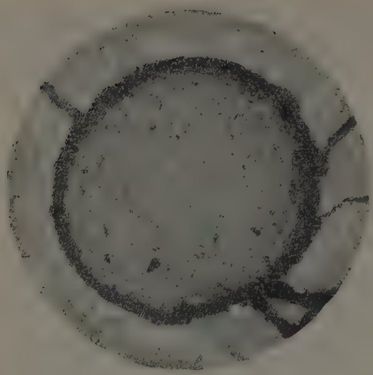


FIGURE 5. Accumulation of metal iron (white) about a gas bubble. Reflected light; magnification X 86.

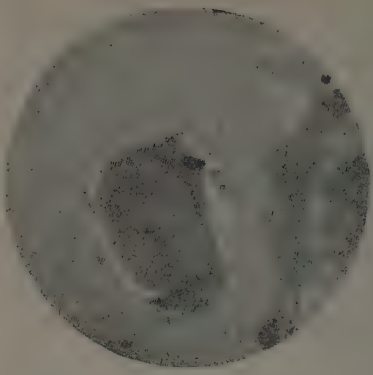


FIGURE 6. Penetration of metal iron fringe (white) into a gas bubble. Reflected light; magnification X 125.

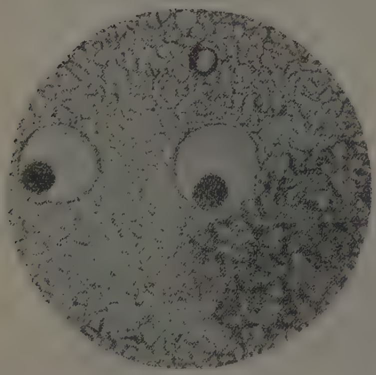


FIGURE 7. Metal iron droplets (black) in gas bubbles. Prismatic grains are of pseudowollastonite. Passing light, without analyser; magnification X 60.

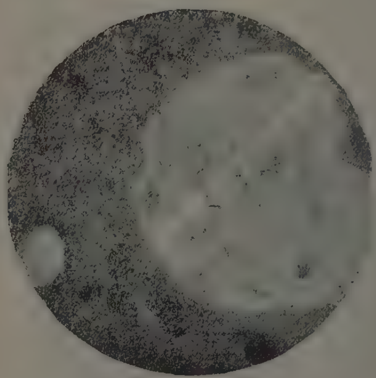


FIGURE 8. Globule of metal iron, in cross section. Reflected light; magnification X 63.

large concentrations of copper, nickel, cobalt, manganese, and other metals, from impurities extracted from granite or syenite. The copper concentration, for instance, rises tens and hundreds of times. The amazingly uniform character of the process of coalescence and the loss of metal from the melt, and the universality of this process, are emphasized by the fact that most of these elements are present in the source rocks in such small amounts as to elude the most sensitive spectrum analysis, whereas their concentration in the globules is quite appreciable.

Such a nice extraction apparently should be ascribed to the atomic state in which the metals are present in the melt as a true solution; and to the above-described character of differentiation of such a melt.

The flotation of matter with the help of gas bubbles is also observed in certain metallurgical processes. In nonferrous metallurgy, for instance, the matte drops are commonly buoyed by sulfur dioxide bubbles adsorbed by the surface of these drops. According to A.N. Vol'skiy [8] such a flotation might become one of the industrial methods of separation of liquid phases in metallurgy. Indeed, an even transfer of solid metal particles by gas bubbles is now being accomplished in industry; for instance, in the

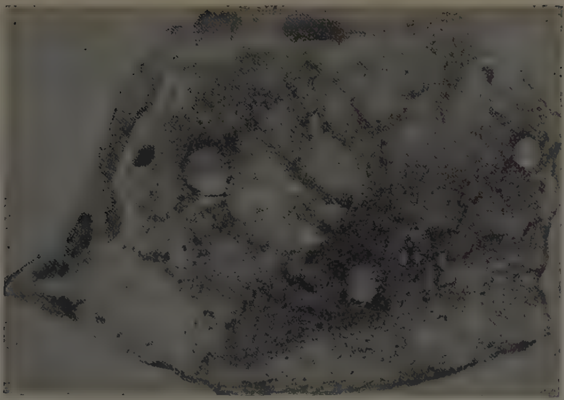


FIGURE 9. Spherules of metal iron on the surface of crystallized melt of granite and limestone. Magnification X 4.5.

separation of copper and lead, the lead bath is treated with compressed air or steam, to expedite the flotation of solid particles. The air or steam bubbles, in their upward movement, carry along the suspended solid particles [35].

The Potter-Del'prat flotation method has been known since 1901. In this method, finely pulverized ore is mixed with sulfuric acid and is heated by steam to 70° C. Hydrogen sulfide bubbles, formed in the reaction of the acid upon sulfide minerals, carry their particles to the surface. If the ore contains a sufficient amount of carbonate salts, carbon dioxide gas bubbles are also formed and considerably expedite the flotation. In modern flotation methods, with compressed air or with stirring, a multitude of minute ore bubbles are formed. These bubbles in their upward drift, gradually coalesce into bubbles large enough to carry up the mineral particles which adhere to them.

The entire process of the ore substance loss from a magmatic melt, similar to the froth flotation process, breaks up into several stages: a) the emergence of very fine droplets of the ore phase because of the liquation; b) coalescence of these droplets; and c) upward drift of the droplets and their further accumulation.

The motion of solid, liquid, and gaseous particles in a liquid medium is determined by the well-known Stokes law. The motion of liquid drops in a liquid medium is described more precisely by the Rybchinskiy-Adamar formula [22]. A liquid particle suspended in a liquid medium will move either up or down, acted upon by a differential force of gravity and the hydrostatic pressure, and against the corresponding resistance of the medium. From the Rybchinskiy-Adamar equation,

$$v = \frac{2r^2g\,(d_1 - d)}{3\eta} \cdot \frac{\eta + \eta'}{2\eta + 3\eta'}$$

or the sinking or floating velocity of the drops is directly proportionate to the square of the drop's radius and to the density difference of the drop and the medium; and inversely proportionate to the viscosity of the medium. In the above equation, v is the constant velocity of the drop, in cm/sec; r is the radius of the drop, in cm; d_1 is its density, in g/cm^3; η is the viscosity coefficient for the medium, in poises; η' the same for the drop; and g is the acceleration of gravity, 981 cm/sec^2.

With $d_1 = d$, it is obvious that $v = 0$, and there will be no differentiation. With $d_1 > d$, the drop will sink; with $d_1 < d$, it will float.

Within certain limits, and especially for more viscous liquids, this formula is applicable to the motion of gas bubbles. However, the character of movement for gas bubbles more than 0.01 cm diameter, is substantially modified in accordance with the so-called Reynolds number

$$Re = \frac{vr}{\nu},$$

where v is the velocity of the bubble; r, its radius, and ν is the kinematic voscosity of the liquid through which the bubble is moving.

The coagulation and coalescence of the ore-substance droplets and the gas bubbles

begins at the very moment of their emergence. The rate of growth of both is especially great in their motion. Coalescence, a union of droplets and bubbles becoming a single whole, is a spontaneous process related to the decrease in the free surface energy as a result of the decrease in the total surface. In its mechanism, it is reminiscent of collective crystallization.

Coalescence is determined by two causes: the probability of collision and the probility of cohesion. The probability of collision depends first of all on the temperature which determines the velocity of the random motion of particles, and on their concentration. The probability of cohesion depends on a number of factors. According to Smolukhovskiy, each particle is surrounded with a sphere of attraction; as soon as another particle is caught in that sphere, a union of the two results. The average value of the attraction radius for a particle is 2 to 3 times larger than the radius of the particle itself [8].

A liquid surface is known to possess an appreciable adsorption capacity. For this reason, the upward transportation of the ore-substance droplets, as well as their preceding coalescence is determined, besides their own coagulation, by their adsorption of gas bubbles or else by their adhesion to larger bubbles. A direct cause of such adhesion is an increase in mutual attraction forces. The phenomena of adsorption, wetting, adhesion, and flotation are closely related. The adhesion of droplets to the gas bubble, like the coalescence of the droplets or gas bubbles, is a result of the tendency of the free surface energy to attain its minimum. According to A.N. Frumkin et al (as quoted in [39]), the adhesive force acting between a gas bubble and a liquid droplet is

$$L = 2\pi\alpha\delta_{12}\sin\theta - (\pi\alpha^2 p - \pi\alpha^2 P),$$

where α is the radius of the contact area; δ_{12} is surface tension at the melt-gas interface; θ is the rim angle of wetting; p is the gas pressure on the bubble's walls; $\pi\alpha^2 p$ is the gas pressure within the bubble on the adhesion area, P is the hydrostatic pressure at the adhesion level, $\pi\alpha^2 P$ is the hydrostatic pressure on the contact area.

On the other hand, the magnitude of the gas adsorption at the liquid surface is determined by equation [9, 31]:

$$T = -\frac{C}{RT} \cdot \frac{\partial\delta_{gfi}}{\partial C}$$

where R is the gas content; T is absolute temperature; C is concentration (more precisely, activity) of the dissolved gas; σ is surface tension at the gas-fluid interface. In the gaseous state, the area of the adsorbed surface film is a function of the temperature and "surface pressure," even as the volume of the gas is a function of the temperature and pressure. The laws connecting the area with the surface pressure and temperature are identical to those uniting the gas volume with the applied pressure and temperature, with even the constant remaining the same. With a pressure rise, the gas film of the droplet surface is condensed; it may solidify if the temperature is sufficiently low.

The gas bubbles, like the ore-substance droplets, coalesce spontaneously. Specifically, V.I. Klassen [20] has shown experimentally that the greater the diameter difference of the contacting bubbles, the shorter the contact needed for their coalescence. Microbubbles (smaller than 0.1 mm) coalesce instantaneously with bubbles having a diameter larger than 5 mm.

The problem of gas-bubble participation in magmatic mineralization is not a new one. K.N. Fenner, in particular, describes the major role of gas bubbles in the migration of minerals, attributing in contradiction to our hypothesis, the loss of metals from magma in the form of gases. According to K.N. Fenner, "some volatiles are eminently qualified as agents of selective accumulation, transfer, and secondary deposition of metal components in magma. Under favorable conditions, small amounts of metal, distributed throughout the magma, can thus be united into large ore bodies" and "Gases ascending in magma, rather than later hydrothermal solutions, are the prime agents of the transfer of metal compounds to the overlying rock." ([32], pp. 74 and 79).

K.N. Fenner gives the following description of the "work" performed by the bubbles ([32], p. 80): "According to the well-known principle, a bubble of one of the above-mentioned gases (H_2O, HCl, CO_2, H_2S, etc.), rising in magma, presents a very low vapor pressure to a chamber collecting other gases. These other gases are driven into the bubble as if the latter were a vacuum, irrespective of the pressure about it. This dynamic action is taken advantage of in technological processes. Under the conditions with which we are dealing, this dynamic action should be very effective, leading to the gathering and venting out of the magma of substances with a low to average vapor pressure." A.M. Bateman ([6], p. 65), in quoting K.N. Fenner, also believes that "the gas transfer should be an effective means of concentration and transportation of metals from magma to the upper part of the magmatic chamber or into the overlying rocks; as such it plays an important part in the formation of mineral ore deposits."

It is pertinent to recall here that S.S. Smirnov ([28], pp. 152, 158) regarded the Fenner scheme "the most perfect among the extant hypotheses," and pointed out that "the differentiation mechanism for ore-carrying fluids, as conceived by K.N. Fenner, undoubtedly presents many advantages over the Greyton-Ross evolutionary ideas on the origin of these fluids."

The gas bubbles, with their useful load of metals, ascend in a common front and truly vertically, only in a homogeneous liquid medium. In the presence of hard rocks of the overburden or of the solidified outer parts of the intrusion itself, such a movement will be interfered with, and the gases will be forced to find other, unobstructed routes, in their upward trend. They will drift toward segments structurally favorable for that purpose, and they will concentrate into definite streams. The gas escape will not take place over the entire melt surface, but will be localized in narrow segments, promoting an even more intensive segregation of ore substance and the formation of large ore bodies.

Ore bodies are formed, unfailingly, in disturbed segments of the overburden, where the excaping gases take advantage of assorted fractures, breaks, etc. We succeeded in observing such a phenomenon where the melt solidified before the loss of ore substance. This occurred during the laboratory experiments in fusing and crystallization of silicate rock mixtures with limestones, when the ore substance did not have time to reach the surface and was deposited in fissures of the solidified melt (Fig. 10).

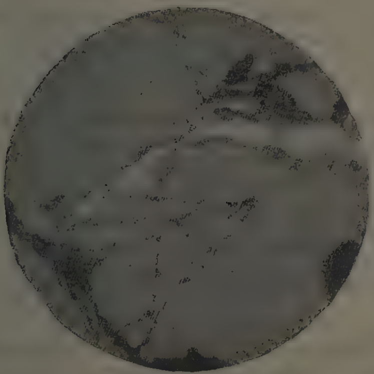


FIGURE 10. Segregations of metal iron (white) in fissures in a solidified melt of granite and limestone. Reflected light; magnification X 86.

In a few places, the gases themselves play the part of a tectonic factor, in performing the mechanical work of disturbing the overburden rock, as they follow and enlarge their path. Geologic instances of this, with the formation of the so-called gas breccias have been collected by D. L. Reynolds [40]. At least in two instances described by him (Sudbury, Ontario; Bull-Domingo, Colorado), the breccia is accompanied by ore. Interesting data on the relation of the Angara-Ilim iron ore deposits with "volcanic" vents are cited by P. Ye. Offman [27]. Of interest in the same connection is the second layer of the Techensk magnetite contact-metasomatic deposit in the middle Urals, which has a distinctive vertical-funnel form, with brecciated rocks inside.

The presence of structurally favorable paths of escape for gases, in the processes of assimilation of limestones, has been confirmed by numerous geologic facts testifying to such assimilation.

In order to realize this assimilation of limestones, i. e., of a chemical interaction with a generation of carbon dioxide gas, a continuous venting of that gas out of the system is necessary. Otherwise, in accordance with the law of active masses, CO_2 will soon attain equilibrium tension and the reaction will cease (equilibrium tension for CO_2, at $t = 903°$ C., is 1 atm; 5).

The performance of Vesuvius is a good example of CO_2 activity. According to A. Rittmann and others [17, 41], the assimilation here determines not only the petrographic character of the lavas but all of Vesuvius activity in historic time.

The limestone assimilation raises the gas tension in magma and thus sustains the life of a volcano.

To be sure, as has been mentioned above, the escape of metals is not the only way to segregate the ore substance from a silicate melt. With different compositions of the mother melt, in the presence or absence of gases, and under different conditions, the ore segregation process may be terminated at different conditions, the ore segregation process may be terminated at different stages with the formation of an ore dispersion alone, or of ore bodies in the source rocks. Droplets of the ore substance are not always carried upward by the gases; their segregation and concentration may proceed, contrariwise, as a result of the sinking to the lower depths of the melt by gravity. However, in all instances and for any type of igneous ore deposits proper, the segregation mechanism for the ore substance and for its coalescence remains the same.

Conclusions and Some Geologic Considerations

In summarizing, a magma presents an ion-electron microheterogeneous liquid containing along with ions in solution, in atomic

state, or as sulfides; iron, chromium, nickel, copper, cobalt, and a number of other metals. The tendency of a magmatic melt to differentiation is inherent in its inner structure, in its microheterogeneity. The above-named elements are unavoidably segregated by means of liquation which takes place with the change in the composition of the melt, or with a drop in its temperature, in the process of intrusion. One of the most important factors in the segregation of iron and a number of other metals from a silicate melt, in liquid state, is its interaction with limestones or other calcium-rich rocks. Their fusing not only lowers the solubility of metals and sulfides which are dissolved in the melt, but also leads to the displacement from the melt of that portion of ore-forming elements, primarily of iron, which is present there in ionic form.

The ore substance, segregated in very fine drops, coalesces. In granitoid rocks, it is then carried by the gas bubbles into the upper, solidified portions of the melt into the overlying rocks, in a manner similar to froth flotation. In the process of escape a further segregation of the ore substance bubbles takes place; and with the gas bubbles disposed in streams along definite, favorable tectonic paths, and under proper conditions, deposition can take place with the formation of large ore bodies -- first of all of a contact-metasomatic type, and of certain hydrothermal ore deposits with greater penetration into the overlying rocks.

In gas-poor and less viscous ultrabasic and basic melts, no loss of the ore substance takes place. It is instead deposited in the source rocks themselves, forming different types of magmatic deposits proper, or of ore deposits determined by magmatic metasomatism.

The form of occurrence for a chemical element predicts its fate in the evolution of the magmatic melt. Two distinct groups of metallogenic elements are discernible here, diverging along two lines of the magmatic and postmagmatic processes of mineralization. The first group includes all elements which, being present in the melt in atomic state or in type MeS compounds with metal electron bonds, form an electron liquid. For one reason or another, they become segregated from the silicate melt in liquation, to form an independent phase. This occurs probably at the initial stages of the intrusive magmatic hearth. Here belong, first of all, elements which produce commercial concentrations in properly magmatic and contact-metasomatic deposits, i.e., iron, titanium, chromium, platinoids, nickel, cobalt, copper, etc. Upon the segregation, these metals concentrate in the source rocks or else are picked up by the large gas bubbles and carried out of the melt.

The second group of metallogenically interesting chemical elements remains in the ion state as a component of the silicate melt. In the evolution of the latter, brought about by the falling temperature, the second group is accumulated in its residue or in differentiates, according to the current concept of the formation of postmagmatic ore deposits. Especially characteristic in this respect is the behavior of beryllium and tin, the typical representatives of the second group. It has been experimentally established [11] that BeO and SnO_2, unlike iron, zinc, and other metals, fully mix with SiO_2 in their molten state. The interaction energy of these atoms with oxygen is so close to that of silicon, that they are mutually interchangeable in the formation of common groups with oxygen. For this reason, the cybotactic segments in such liquids do not possess any sharp distinctions, and the segregation (liquation) does not take place. This is what determines the predominant accumulation of beryllium and tin in pegmatites and greisens. Additional factors are necessary for these elements to concentrate in ore deposits of the first group.

The beryllium accumulation, for instance, in skarn deposits, is related to the high fluorine content in a given magma. The extracting power of fluorine for beryllium is very great [2].

The different form of occurrence of chemical elements in the melt, and the different character of the segregating processes, which bring about the spatial and temporal differentiation of pegmatites and ore deposits, may shed some light on their relationship which, according to S. S. Smirnov [28, p. 153], "is one of the most urgent problems of ore origin."

A number of chemical elements, especially such widespread ones as iron, can be present in a melt simultaneously in ionic and atomic forms. As such, they correspondingly enter the composition of ore-forming minerals and are segregated in ore deposits. Iron, present in a melt in atomic state or in compounds with a FeS type or even Fe_2O_3 bond, undergoes liquation and then enters the ore deposits, being fixed in rocks only in small amounts as accessory magnetite. Iron, present as Fe^{+2} and Fe^{+3} ions, enters the composition of ore-making silicates. It should be emphasized that only a small portion of iron enters the ore phase, the bulk of it remaining in the silicate melt. Accordingly, a search for a magmatic-origin iron ore beyond the source intrusion is quite superfluous. The simplest computations show that

the ore iron accounts for a comparatively small percent of its overall content in a generally iron-poor granite or syenite melt. For instance, if all of the iron of Vysokaya Mountain and the surrounding ore deposits be returned to the syenites of its origin, its content in those rocks -- only within the triangle Yevstyuninskoye--Lebyazhinskoye--Vysokaya Mountain, and to depths of no more than 500 m, would be increased only 0.3%, by volume. Similar insignificant contents mark the intrusions with which are connected the largest ore deposits of the Nagnitnaya and Blagodat' Mountains.

Titanium, too, plays a dual role in the melt. As present in ion state in silicates, it forms complex anions and enters the silicon-oxygen tetrahedrons. On the other hand, it accumulates in magmatic titaniferous magnetite ore deposits.

As is well known, several genetic types are identified among titaniferous magnetite ore deposits in pyroxenites and gabbros, with also a difference of opinion existing as to their origin [21, 36]. Chromite deposits, associated with ultrabasics, are subdivided into a number of types, depending on the conditions of their formation [29]. However, the above-described mechanism of segregation from a silicate melt by way of the indispensable liquation stage is common to all of those types, as it is to all magmatic ore deposits proper including the sulfides. The variety of conditions under which this segregation takes place -- including the difference in the melt composition, the interaction with the lateral rocks, the difference in the separation time dependent on the different thermodynamic conditions -- leads to the diverse relationships between ore bodies and the enclosing source rocks and to the variety of the ore-deposit types observed in nature. Specifically, an ore substance, having been segregated early, may be the last one to crystallize.

The differentiation of a liquid ore substance, i.e., the liquation of a magmatic melt into a silicate and ore portions, has been confirmed by numerous experiments, especially in the field of silicate-sulfide systems. The experiments of R. Fisher [34] demonstrate the possibility of segregation of an ore phase from a liquid silicate melt, of the Kirun-type magnetite deposit. The direct geologic proofs of the origin of the liquation stage in the formation of magmatic ore deposits are few. This is because, as correctly noted by A.N. Zavaritskiy [16], no evidence of an earlier differentiation process in the liquid state is left in the crystallization of an ore liquid. "A clean-cut evidence of liquation is hardly to be expected, and the lack of such evidence does not deny its possibility" [16, p. 779]. A.N. Zavaritskiy himself regards as such evidence, the chorioid texture of chromite nodules in dunites, which points to the growth of crystals from periphery to the center [16, 29].

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STRATIGRAPHY AND METAMORPHISM OF ANCIENT ROCKS IN THE CENTRAL PART OF THE BARGUZINSK RANGE[1]

by

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Thick Precambrian and lower Paleozoic deposits and assorted extrusives are developed throughout the vast area of the Barguzinskiy Range. Different students hold contradictory views on the Precambrian and lower Paleozoic stratigraphy of this region. The finding of a fauna of archaeocyathids, trilobites, and brachiopods [9] in the Biram'ya basin made it possible to refine the stratigraphy of the Angara-Barguzin interfluve region. However, the position of individual formations in the stratigraphic section remains controversial.

The metamorphic rocks of this region were first described by P. Eskola who relegated them to the Algonquian and correlated them with the Precambrian greenstone facies of Finland [11].

A composite stratigraphic column for the Angara-Barguzin mountainous region was drawn by V. V. Dombrovskiy, in 1939. At the base of the section he put the Barguzin formation of crystalline limestones interbedded with calcifers, crystalline schists, and gneisses. The age of that formation was determined as Archaean, with a reservation that there is some evidence of its overlying upper Proterozoic rocks which V. V. Dombrovskiy lumped into the Nyandoninskaya formation. The upper part of the section he assigned to the Lower Cambrian, dividing it into three series (Ukolkitskaya, Katerskaya, and Biram'inskaya).

In opposition to V. V. Dombrovskiy, N. I. Fomin associated the Barguzin formation with the lower Proterozoic. Without getting involved in the problem of metamorphism, he generally outlined the lower intensity of the Baguzin formation metamorphism as compared with that of the Archaean micaceous formation. The Nyandoninskaya formation was supposed to be upper Proterozoic or Lower Cambrian, correlated by N. I. Fomin with the ternary Baikal complex.

L. I. Salop, who did not regard the Barguzin formation as an independent stratigraphic unit, included its rocks in the upper Proterozoic Nyandoninskaya formation. He explained the intensity of the Barguzin formation metamorphism by the "regional-contact" effect of upper Proterozoic granitoids of the Barguzin complex.

S. A. Gurulev believes that the Namaminskaya formation is the base of the standard section. According to him, the upper Paleozoic section opens with the Nyandoninskaya formation carrying at its base conglomerates, sandstones, and limestones. A Lower Cambrian fauna was subsequently found in the limestones [9]. These rocks, according to S. A. Gurulev, are overlain by the Nyandoninskaya formation proper. The Barguzin formation lies at the top of the section, with a gradual transition from the underlying Nyandoninskaya formation.

After the finding of the trilobite, archaeocyathid, and brachiopod fauna in the Biram'ya Basin, P. Ch. Shobogorov [9], without modifying the stratigraphic sequence of S. A. Gurulev, switched the Namaminskaya formation to the upper Proterozoic, and all of the overlying formations to the Lower Cambrian.

It appears from this brief review and from Table 1 that the position of the Barguzin formation in the standard stratigraphic section has been very controversial because, in each instance, the correlation was made either on the basis of its high degree of metamorphism (Archaean to lower Proterozoic) or on scattered data on its occurrence (Lower Cambrian). As became clear after a detailed study of control Precambrian and Lower Cambrian sections, and from the preliminary geologic maps on a scale of 1:200,000 (A. V. Kolesnikov, V. I. Navil', P. Ch. Shobogorov, Z. M. Anisimova, V. G. Belichenko, and A. S. Yeskin), the problem of the age of the Barguzin formation can be solved only by a comprehensive study of the stratigraphy and the metamorphic processes.

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[1] **Stratigrafiya i metamorfism drevnikh tolshch tsentralnoy chasti barguzinskogo khrebta.**

Table 1

Stratigraphic Columns of the Angara-Barguzinskiy Mountainous Region, According to Various Authors

After V.V. Dombrovskiy and A.K. Guseva (1939)	After A.I. Salop (1947)	After N.I. Fomin, I.I. Shcherbinin, and F.S. Kotskikh (1947)	After S.A. Gurulev, et al (1953)	After P.Ch. Shobogorov and V.M. Gizh (1954)	After V.A. Kolesnikov and Z.M. Anisimova (1957)
Lower Cambrian	Kodar formation (Pt_2-Cm_1)	upper Proterozoic-Lower Cambrian	upper Proterozoic	Nyandoninskaya series (Cm_1)	Biram'inskaya series (Cm_1)
Biram'inskaya	Molchokskaya	Nyandoninskaya	Barguzin	Barguzin	Turikskaya
Katerskaya	Tukolal'skaya		Nyandoninskaya	Nyandoninskaya	Biram'inskaya
Ukolkitskaya	Turikskaya			Biram'inskaya	Irkandinskaya
				Ukolkitskaya	
Proterozoic	Katerskaya formation (Pt)	lower Proterozoic	lower Proterozoic	upper Proterozoic	Katerskaya series (Pt_2)
Nyandoninskaya	Yanchuyskaya	Barguzin	Namaminskaya	Namaminskaya	Barguzin
Archaean (?)					Nyandoninskaya
Barguzin	Nyandoninskaya				
	Anadzhanskaya				
	Ukolkitskaya				

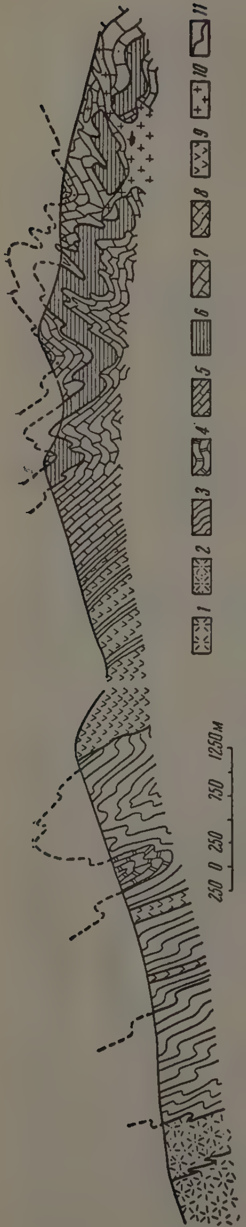

FIGURE 1. Cross section along the Niromakit Brook and Niromakit-Topo watershed.

Nyandoninskaya formation: 1-2 -- extrusives, tuffaceous shales, and tuffaceous sandstones; 3 -- metamorphic schists; 4 -- dark pelitomorphic limestones; 5 -- fine-grained gray marbles; 6 -- quartz-carbonaceous schists (microquartzites and graphite-quartzites).

Barguzin formation: 7 -- medium- to coarse-grained marbles; 8 -- marbles interbedded with quartzites and crystalline schists and gneisses; 9 -- extrusives of an intermediate composition; 10 -- Barguzin granitoids; 11 -- conditional boundary between the Barguzin and Nyandoninskaya formations.

According to our own data, the base of the standard ancient section in the central Barguzinskiy range is represented by the Nyandoninskaya formation. Its lower part is made up of ophiolites, tuffaceous shales, and tuffaceous sandstones with thin limestones, quartz-sericite-chlorite, and quartz-carbonaceous and other schists.

The middle part of the Nyandoninskaya section is characterized by quartz-carbonate-sericite, sericite-chlorite, quartz-sericite-carbonaceous and amphibole-chlorite schists, microquartzites, and limestones. The limestones are in the ascendancy beginning with the upper part of the section and are predominant in the overlying Barguzin formation. The Nyandoninskaya formation sections were studied in detail along the Niromakit Brook, Topo River, and in the upper course of the Namama River. The most complete is the Niromakit section, where the brook cuts it across the strike (Fig. 1). Here, the section begins with metamorphosed extrusives, tuffaceous shales, and tuffaceous sandstones, which change upward to a 1500 m thick sequence of assorted schists: quartz-sericite-chlorite, quartz-biotite-sericite, quartz-carbonate, locally altered to quartz-biotite-amphibole and quartz-amphibole-pyroxene hornstones. In the upper course of the Niromakit, the metamorphics give place to quartz-biotite-garnet, quartz-biotite-carbonaceous and quartz-biotite-chlorite schists.

Limestones, 200 to 250 m thick, crop out along the middle course of the brook, where they rest on the schists.

Higher up in the section, the schists contain progressively more limestone beds, whose thickness gradually increases. It is characteristic that going toward the pass to the Topo Valley, fine-grained limestones gradually change to the coarse grained, whereas the above-described schists change to tremolite-biotite, epidote-hornblende-biotite, and actinolite-garnet schists.

Black quartz-carbonaceous schists (microquartzites) appear in the upper part of the section, where they change to gray quartzites and are interbedded with limestones.

This sequence, 800 to 900 m thick, is transitional from the Nyandoninskaya schist section proper to the overlying Barguzin carbonate formation.

In the vicinity of granite massifs (in the near-contact zone and in xenoliths), the Nyandoninskaya rocks are represented by biotite, biotite-hornblende, dimicaceous, garnet-biotite-hornblende gneisses and schists.

The Barguzin formation, which makes up

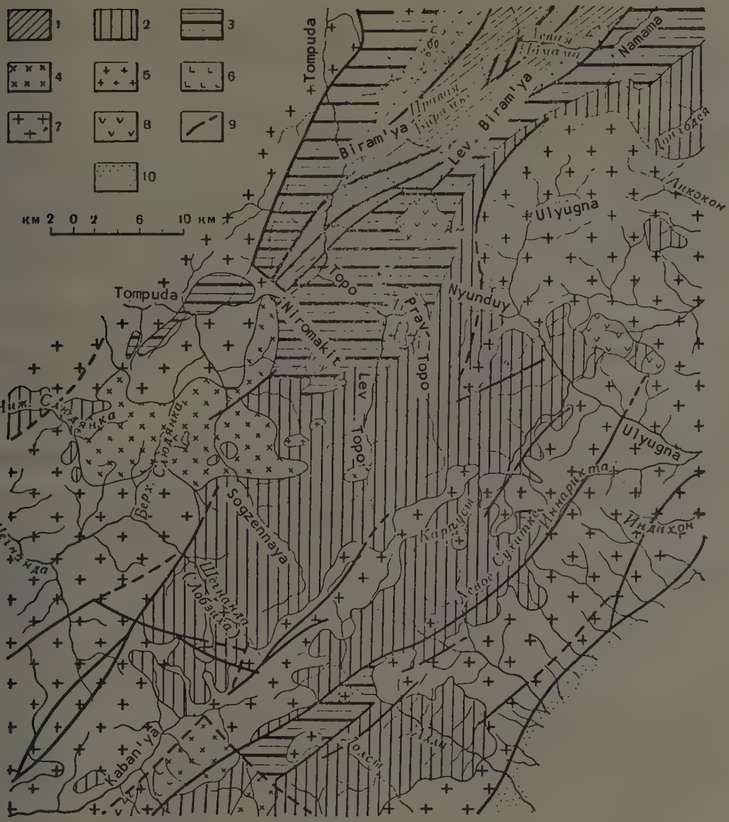

FIGURE 2. Generalized geologic map of the central part of the Barguzinskiy Range.

1 -- Lower Cambrian (Biram'inskaya formation) — upper Proterozoic (Katerskaya formation); 2 -- the Barguzin formation; 3 -- the Nyandoninskaya formation.

Conditionally Caledonian intrusive complex: 4 -- monzonites; 5 -- granites, granodiorites; 6 -- gabbro-diabases. Upper Proterozoic intrusive complex: 7 -- granitoids (Barguzin complex); 8 -- gabbros, gabbro-norites, gabbro-diorites, diorites (Ikatskiy complex); 9 -- fault traces; 10 -- Quaternary deposits.

the core of a large synclinorium, is well developed in the central part of the Barguzinskiy Range (Fig. 2).

Rocks of the Barguzin and Nyandoninskaya formations, crop out as remains of a large granite batholith roof, dipping very gently away from it. The batholith itself is fully exposed along its axial part, and partially exposed in deep gorges cut by the streams in its slopes (1.5 to 2.0 km deep). Because of that proximity, the Barguzin formation has been strongly metamorphosed, throughout a considerable area, even where the upper Proterozoic granitoids do not reach the surface. Predominant among the Barguzin-formation rocks are crystalline limestones carrying carbonaceous matter and graphite scales, in the zones of high metamorphism. Of a more subordinate character are calcifers of a forsterite-pyroxene composition; quartzites; biotite-hornblende and biotite-pyroxene gneisses, and crystalline schists, forming more or less thick beds in the limestones.

It should be noted that injectional analogues

of the gneisses have been observed at the immediate contact with the granites. The visible thickness of the Barguzin formation is 1500 to 2000 m.

The upper member of the standard section is represented by the Biram'inskaya series of the Lower Cambrian, which has been deposited with a stratigraphic break and consists of basal conglomerates, fauna-bearing limestones [9], limestone conglomerates, and sandstones. Lower Cambrian rocks are located in a large synclinal fold complicated on its limbs by normal-type faults.

We assign the Barguzin and Nyandoninskaya formations to the upper Proterozoic, for the following reasons: first, they are overlain unconformably by the faunally characterized Lower Cambrian deposits; second, because the Nyandoninskaya-Barguzin section is identical to that of the upper Proterozoic from the central part of the Ikatsk Range [5] and fairly similar to the ternary Baikal complex [4].

Widespread in the central part of the Barguzinskiy Range are the Barguzin complex volcanics, represented chiefly by granites, syenites, and granodiorites. Considerably less common are isolated minor bodies of basic rocks (gabbro, gabbro-norites, gabbro-diorites, diorites). Among the younger post-Lower Cambrian formations are gabbros, gabbro-diorites, granitoids, and, tentatively, monzonites. In their bulk, the massifs of these rocks are clearly inferior to the Barguzin granitoids.

The following varieties have been recognized among the latter: coarse-grained hornblende-biotite granites and syenites; fine- to medium-grained hornblende-biotite granites and granodiorites; pegmatites, and aplites. Granitoids of the near-contact segments are gneiss-like. According to our observations the formation process of the Barguzin granitoid massifs is undoubtedly related to granitization in the most general meaning of this term. This is suggested by such facts as the preservation of the elements of occurrence for the xenoliths, the injection contacts, the evidence of feldspathization, and the gneiss-like aspect. The latter is a relict feature inherited from the originally-stratified metasedimentary formations which have undergone granitization.

A telling proof of the stratigraphic unity of the Barguzin and Nyandoninskaya formations is the community of their metamorphism brought about by the Barguzin granitoids. However, the problem of their age cannot be solved definitely without taking into account the phenomena of the multiphase metamorphism and the geologic history of the region.

On the basis of the material on hand, the following outline of metamorphic phases and facies is conceivable:[2]

I. Regional metamorphism (sericite-chlorite facies).

II. Contact metamorphism.

1. Metamorphism connected with the Barguzin granitoids:
   a) biotite-chlorite facies;
   b) biotite-garnet-actinolite facies;
   c) amphibolite facies;
   d) almandine-pyroxene-hornblende facies.
2. Metamorphism connected with post-Lower Cambrian Intrusions.

III. Metamorphic phenomena in Lower Cambrian rocks.

I. REGIONAL METAMORPHISM

The area of regional metamorphism, mapped (Fig. 3) as a northeasterly trending belt, stretches from mouth of Topo River to the upper course of Namama River. The boundaries of the area are vague because processes of the later contact metamorphism in rocks at some distance from the igneous contacts took place under thermodynamic conditions very similar to the regional metamorphism which is characterized by its uniformity and consistency over a wide avea. The regional metamorphism has been expressed not only in a recrystallization of the rocks but also in the formation of a definite complex of characteristic minerals, first of all chlorite and sericite, also of weakly colored low-temperature amphiboles of the actinolite type, and in a few places, biotite. All these minerals determine the character of parageneses of the regional metamorphism facies. Inasmuch as the metamorphism of this phase is essentially an initial stage of the metamorphic evolution of chemically different "para" and "ortho" rocks, the number of new minerals formed in this process is very small.

Rocks affected by the regional metamorphism are represented by gray to greenish-gray, very fine to fine-grained schists and dark-gray limestones. Their characteristic minerals are chlorite, sericite, quartz, carbonates, with some carbonaceous matter evenly dispersed in very fine particles and responsible for the dark gray to black coloring; a small amount of biotite represented by weakly pleochroic minute scales with irregular outlines; titanomagnetite; iron sulfides,

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[2] Postmagmatic processes and those of a mutual contact effect of intrusive complexes are not considered in this paper.

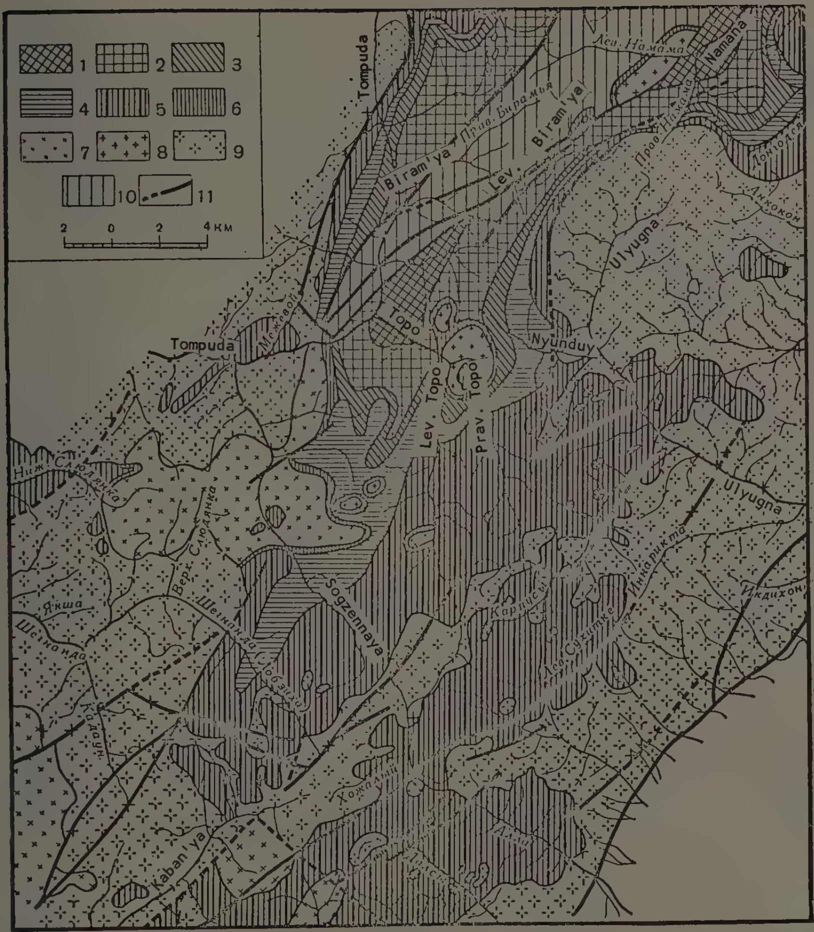

FIGURE 3. Facies and phases of metamorphism in the central Barguzinsk Range.

Regional metamorphism: 1 -- sericite-chlorite facies. Contact metamorphism connected with the Barguzin granitoids: 2 -- biotite-chlorite facies; 3 -- biotite-garnet-actinolite facies; 4 -- amphibolite facies; 5 -- almandine-pyroxene-hornblende facies; 6 -- contact metamorphism connected with the allegedly Caledonian intrusions of granitoids and monzonites. The alleged Caledonian intrusive complex: 7 -- monzonites; 8 -- granites, granodiorites; 9 -- upper Proterozoic granitoids; 10 -- Cambrian deposits; 11 -- fault traces.

and relict minerals of the original clastic rock: feldspars and tourmaline. All these rocks are characterized by relict features with elements of blastosilty and blasto-psammitic textures. These alternations are peculiar to the sericite-chlorite facies of metamorphism (the green schist facies).

The regional metamorphism, in our opinion, is related to folding processes which took place prior to the intrusion of the Barguzin granitoids.

II. CONTACT METAMORPHISM

1. Metamorphism related to the intrusion of the Barguzin granitoids is widespread within the Barguzinskiy Range, within whose axial part, it is at its maximum and represents a thermal isochemical type of metamorphism without intensive manifestation of metasomatism.

A peculiar combination of the form of granitoid bodies with the enclosing rocks, leading in most instances to nearly flat contacts, has resulted in a wide areal development of contact metamorphism.

In areas where steep contacts of the granitoids are combined with a dip of the enclosing rocks away from the intrusives, the areal extent of the temperature stages narrows (in the plan) to a minimum (the Ulyugna-Levaya (left) Biram'ya watershed).

The entire range of the temperature stages is present, from the lowest biotite-chlorite phase close to (dynamic) metamorphism, of the local phase of the regional metamorphism, to a stage approaching granulite [7, 8] or the Aldan-Slyudyanka facies of D.S. Korzhinskiy [1, 2].

As seen in the maps (Figs. 2, 3] the boundaries of the several facies do not coincide with those of the formations but cross them, instead. This is because different segments of the formations fall into areas of different thermodynamic conditions, with the relative position of the emplacing rocks and granitoids being the decisive factor in the creation of these conditions. A similar picture of the independence of outlines of the stages of thermal metamorphism, of the tectonic structures has been noted by Ye. Bederke [10] for the Alps.

We have taken for the basis of the facies differentiation the results of study of mineral associations and of textural-structural features of the rocks, characteristic of the given thermodynamic stages.

a) The biotite-chlorite facies (Fig. 3) is characterized by an intensive formation of biotite in the original argillaceous rocks, where it acquires the importance of a leading mineral, being present in scales and porphyroblasts, commonly sieve-like (inclusions of quartz, chlorite, sericite), intensely pleochroic, with a "transverse mica" stricture [6].

Chlorite, along with sericite, is decidedly subordinate. There is a considerable amount of weakly colored, low-temperature amphibole.

Carbonaceous matter in the argillaceous rocks is concentrated in clots which are responsible for its spotty texture.

Uneven partial recrystallization takes place in the carbonate rocks along with the concentration of the carbonaceous matter into clots.

Rocks of the biotite-chlorite facies are characterized by microscopic granoblastic and epidogranoblastic textures, almost always in combination with the porphyroblastic (at the expense of biotite).

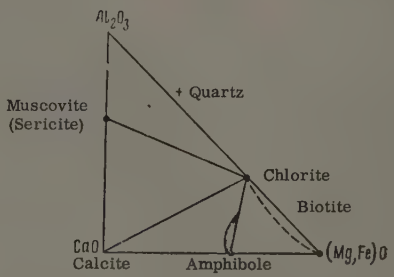

FIGURE 4. Mineral parageneses of the biotite-chlorite facies.

The mineral parageneses of this facies are presented in Figure 4, which illustrates the Al_2O_3-CaO-(Mg, Fe)O system, with an excess of SiO_2. The appearance of mica (biotite, muscovite, and a colorless mica) in almost all argillaceous-silicate and argillaceous-carbonate rocks is especially interesting, as it suggests a considerable K_2O content.

b) The biotite-garnet-actinolite facies is shown on the map as a narrow sinuous band extending from Niromakit Brook, across the Topo River, toward the upper courses of the Namama and Tompuda.

In the environment of this facies, actinolite has been developed in argillaceous-silicate

rocks with an excess of SiO_2 and K_2O; and biotite and muscovite in these rocks but oversaturated with Al_2O_3 and K_2O. Initial stages of recrystallization in plagioclases are present, in places.

Characteristic here is the appearance of a black garnet,[3] in 3 to 5 mm grains with rhombododecahedral outlines. There are small amounts of kyanite porphyroblasts with a diablastic texture (incrustations of biotite and quartz). Titanomagnetite of the original argillaceous rocks is altered to aggregates of small grains of sphene. The carbonate rocks have been almost fully recrystallized and rendered lighter in color, with pelitomorphic segments preserved in relicts. The carbonaceous matter, the most sensitive to change in thermodynamic conditions, is altered in rocks of the garnet-biotite-actinolite facies, from clots to individual small graphite scales.

The biotite-garnet-actinolite facies unites the following rock varieties: biotite-mica and kyanite-quartz schists; quartzites; garnet-sericite-biotite, graphite-tremolite-carbonate and quartz-actinolite-carbonate schists; garnet-carrying amphibolites; actinolite amphibolites; and fine- to medium-grained marbles with fine graphite scales. Rocks of this facies are characterized by granoblastic, lepodogranoblastic, and nematoblastic textures.

The bedded basic rocks (gabbros and gabbro-diorites), under the conditions of this metamorphic stage, undergo an amphibolization process.

[3]Composition (in percent): almandine, 59.8; pyrope, 28.7; spessartite, 0.7; andradite, 4.8; grossularite, 2.3; schorl, 3.7. Refraction index is close to 1.780.*

*These data on the mineral composition of metamorphic rocks are not accompanied by a chemical analysis of the rocks and minerals; this renders the author's constructions less convincing, without however detracting from their interest. (Russian editor's note).

Mineral parageneses for the biotite-garnet-actinolite facies are presented in Figure 5.

c) The amphibolite facies is better developed than the preceding one. It forms a belt of varied width: narrowest in the upper reaches of the Levaya Biram'ya River; widest in the Sogzennaya Basin.

This facies is characterized by new mineral formations, not present in the preceding: hornblende, cordierite, andalusite, and biotite, with plagioclase and muscovite more euhedral and nearly free of other mineral impurities. Pyroxene has been observed in isolated small grains with wavy outlines. As in the preceding facies, kyanite is present here, forming prismatic porphyroblasts, along with coarser sphene grains without distinct crystallographic outlines. Graphite scales larger than those of the facies previously discussed, have been observed in graphitic rocks.

The carbonate rocks have been fully recrystallized and altered to medium-grained marbles, with hornblende, plagioclase, and biotite scales present at places contaminated by argillaceous material.

The following varieties have been recognized among the amphibolite facies rocks: amphibolites (common hornblende, plagioclase); hornblende-biotite gneisses; medium-grained calcifers; hornblende-biotite-cordierite and andalusite-cordierite-biotite hornstones; quartzites, and medium-grained marbles with graphite scales. Rocks of this facies possess a granoblastic, nematolepidoblastic, and hornstone texture. Mineral parageneses for the more common rocks of this facies are presented in Figure 6.

d) The almandine-diopside-hornblende facies is distributed throughout a vast area of the most intensively metamorphosed rocks, associated chiefly with the axial part of the

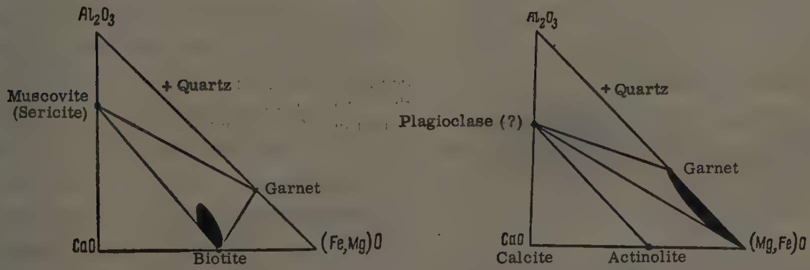

FIGURE 5. Mineral parageneses for the biotite-garnet-actinolite facies.

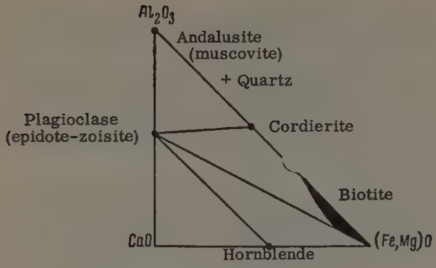

FIGURE 6. Mineral parageneses for the amphibole facies.

Barguzinskiy Range with its numerous granitoid bodies of various sizes and forms.

This metamorphic facies is characterized by an almost complete crystallization of rocks and by a total lack, in most cases, of relicts of low-temperature minerals and of clastic and other textures. Structure of the rocks of this facies are uniform, the gneisses and crystalline schists being banded and the marbles, massif. All of the rocks are medium, rarely coarse-grained, with a granoblastic, lepidoblastic, and similar textures.

Among the minerals characteristic for this facies of contact metamorphism are garnet (close to almandine in its composition),[4] hornblende, monoclinic pyroxene (diopside), plagioclases, biotite, scapolite, carbonates, sillimanite; accessory minerals: sphene, magnetite, and tourmaline. Forsterite has been observed in some rocks. The carbonaceous matter in all rocks of this facies has been altered to graphite scales. Diagram Figure 7 shows the mineral parageneses of this metamorphic facies for argillaceous-silicate rocks. We shall consider the individual segments of the diagram.

Segment I. Most important minerals are plagioclase, almandine, sillimanite, with biotite almost always present, and with microcline in intrusive varieties. In its chemical composition and parageneses, this segment corresponds to such rocks as biotite, biotite-garnet, and biotite-garnet-sillimanite gneisses and their intrusive analogues.

Segment II. Index minerals are almandine, hornblende, and plagioclase. Present in varied amounts are quartz and biotite, with microcline in the intrusive varieties. Assorted garnet-hornblende gneisses and crystalline schists are separated in this segment, according to their mineral composition.

Segment III corresponds to rocks of the two main groups: assorted hornblende, biotite-hornblende gneisses, and crystalline schists, of the first group, are transitionally connected with diopside-carrying plagioclase schists and with less common gneisses, of the second group.

Segment IV corresponds to a large number of varieties of Barguzin formation carbonate and silicate-carbonate rocks, most widespread in the area of this facies. The main paragenesis for this segment is the calcite-diopside-plagioclase (scapolite)-quartz association. Forsterite is formed where the silica content is low and there is an excess of magnesium. The following varieties are identified here by their mineral composition: medium- to coarse-grained white marbles with graphite; and calcifers with diopside, forsterite, plagioclase, and quartz.

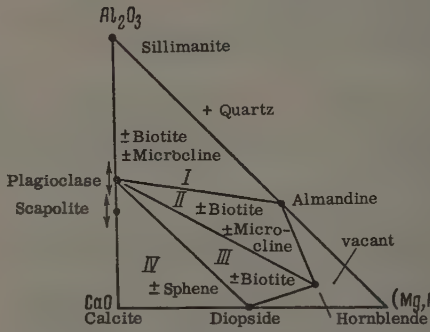

FIGURE 7. Mineral parageneses for the almandine-diopside-hornblende facies.

2. Metamorphism connected with post-Cambrian intrusions. Without getting into the problems of the Cambrian-rock metamorphism as a whole, we shall pause only for near-contact alterations caused by intrusions of the Vitimkanskiy complex. Granites and granodiorites of that complex produce, as a rule, a fairly narrow contact halo, only 50 to 150 m wide in the upper Namama course and in the Biram'ya Basin. Here, the granites cut the Nyandoninskaya conglomerates and sandstones (Cm_1) and green schists (Pt_2). At the granite contact, the conglomerate pebbles are represented by recrystallized limestones; with the cement containing, besides carbonates and quartz, epidote, with an incipient

[4] Composition (in percent): almandine, 71.1; pyrope, 7.6; spessartite, 4.5; andradite, 6.5; grossularite, 9.9; schorl, 0.3. Refraction index, not more than 1.830.

heterogranoblastic texture. The sandstones have been altered to a quartz-carbonate-epidote rock (as much as 20% epidote), with a heterogranoblastic texture; the Nyandoninskaya formation rocks, to assorted hornstones (epidote-pyroxene, hornblende-biotite). The granites are characterized by their higher assimilating capacity. Chlorite and a colorless mica appear in limestones at the granodiorite and diorite contacts. The width of the contact halo here is small (as much as 1.5 m).

Similar contact alterations have been observed about the small granite massifs, along the Topo middle course and in the Sogzennaya Basin; as well as about the monzonite massifs along the Sogzennaya middle course and at the Topo headwaters. At the granite contact along the Topo, the altered rocks are represented by hornstones with garnet (in schist beds) and by skarn rocks (in limestones). The zone is 10 to 20 m thick. It is not well expressed everywhere: where the contact alterations affect the low-temperature rocks (biotite-chlorite facies), a well-defined contact halo is observed; along the southern contact, the effect of granites on more intensively metamorphosed rocks is almost nil. A narrow contact band of hornstones, skarn rocks, and hardened marbles is also present about the monzonite massifs.

It appears from the above that the contact alterations caused by granites and monzonites along the middle courses of the Topo and Sogzennaya do not differ from those observed about the granodiorite and granite massifs which cut the known Lower Cambrian deposits. On that basis, and also because of their similar chemical and mineral composition, granites and monzonites of the Topo and Sogzennaya Rivers are here tentatively assigned to the Vitimkanskiy complex.

Contact alterations associated with the above-named intrusions are superimposed processes leading to the formation of hornstone and skarn rocks whose zone is superposed on the rocks of all preceding metamorphic facies. In localities where hornstones and skarn rocks are superposed on lower degrees of metamorphism, the contact alterations acquire the features of progressive metamorphism; localities subjected to a high degree of metamorphism, on the other hand (the amphibolite and almandine-pyroxene-hornblende facies), acquire a diaphtoresic (retrograde metamorphic) character.

Cambrian deposits differ from the above-described upper Proterozoic complex in their complete lack of evidence of widely developed metamorphic processes. The strictly local alterations which we have observed are associated, as a rule, with post-Lower Cambrian intrusives. It is possible that the alteration of Cambrian rocks elsewhere in the area (a partial recrystallization of limestones, the appearance of chlorite and sericite) are associated with the numerous faults.

In summarizing, we come to the conclusion that the Barguzin and Nyandoninskaya formations form a single stratigraphic complex. This is proven by the absence of a stratigraphic unconformity between them, by their structural unity (the northeastern trend of folding), and the community of igneous rocks which cut and alter them.

The age of these thick sedimentary-volcanic rocks of the Barguzin and Nyandoninsk formations is taken to be upper Proterozoic, because these rocks are overlain unconformably by rocks carrying a Lower Cambrian fauna, and because this section is similar to upper Proterozoic sections of the central Ikatskiy range and of the western Baikal region. The correctness of the age determination for these formations is confirmed by a study of the multiphase metamorphism of this region.

The deep alteration of the Barguzin and partially of the Nyandoninskaya formations was caused chiefly by the progressive contact metamorphism induced by the Barguzin complex (upper Proterozoic) granitoids. For this reason, the relegation of the Barguzin formation to the Archaean, as is done by some students, is groundless.

Archaean metamorphic complexes of eastern Siberia are marked by an outstanding uniformity in the manifestation of the regional metamorphism, without any traces of relicts of the low-temperature associations of the original clastic textures, and with gradual transitions to nearly unaltered rocks generally absent. As pointed out above, the highly metamorphosed Barguzin and Nyandoninskaya formations are marked by a different and peculiar contact type metamorphism, wherein the gradual transitions from siltstones, sandstones, marls, etc., to crystalline schists, marbles, and gneisses have been preserved, in the presence of conditions favorable for a wide areal development of metamorphic rocks of each of these facies.

Paragenetic patterns in the highly metamorphosed rocks under study do not correspond to the associations characterizing the Aldan-Slyudyanka facies [1, 3]. The differences between them are determined by the total lack of hyperstene-carrying crystalline schists among the Barguzin and Nyandoninskaya rocks, in the presence of all components necessary for the formation of such mineral associations. This is explained by the lower intensity of the metamorphic processes which took place in the relatively thin uplifted roof of a large granite batholith,

and in no wise can be associated with the processes of diaphtoresis. Archean complexes of the western Baikal region do not carry any hyperstene rocks, which, in that instance, has been determined by the processes of regional diaphtoresis [1, 3].

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SCANDIUM IN DEPOSITS OF DIFFERENT GENETIC TYPES[1]

by

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Scandium is an element widely dispersed in rocks. Its Clarke Index, according to V. I. Noddack [quoted in 6], is $6 \cdot 10^{-4}\%$ Sc, whereas its average content in various rocks usually does not exceed thousandths of one percent. As a dispersed element in the earth's crust, scandium does not form any significant accumulations which could be called its independent deposits.

Scandium, discovered by Nilson, in 1879, has not as yet found a wide practical application. This is to a certain extent the result of the inadequate knowledge of the physical and chemical properties of this element and its compounds. A substantial reason for this has undoubtedly been the difficulty of obtaining scandium. Up to now, only two scandium minerals have been known, thortveitite and bazzite, both very rare in nature, and which do not form large deposits and are therefore without much practical significance. For this reason, of especial interest are ores and other minerals where scandium is present as an impurity and attains a content much above the Clarke Index [3, 4, 6]. A large number of scandium-bearing minerals (about 2,000) analyzed at the Institute of Mineralogy, Geochemistry, and Crystallochemistry of Rare Elements (I. M. G. R. E.), Academy of Sciences U. S. S. R., has shown that their scandium content fluctuates from 0.01 to 0.2%, i. e., approximately 16 to 300 times greater than its Clarke Index.

Such minerals include cassiterite, wolframite, columbite, zircon, baddeleyite, beryl, micas, some rare earth minerals, etc. At the present time the presence of scandium has been established for a total of about fifty minerals and their varieties. The small number of scandium minerals proper, on one hand, and a fairly sizable number of scandium-bearing minerals, on the other, is explained first of all by the similarity of ion radii of scandium and such common elements as bivalent iron and magnesium, and by the similarity in ion radii, the equivalence of charges and coordination numbers for scandium and rare earths of the yttrium subgroup. Thus, the affinity of Sc^{+3} for Fe^{+2} and Mg^{+2} and for elements of group TR, and to a somewhat smaller extent for Zr^{+4} and Al^{+3}, promotes the isomorphous entry of scandium into many minerals.

Such scandium-carrying minerals are distributed considerably more widely than thortveitite and bazzite, and they form individual deposits. In isolated instances, these deposits (of wolframite, cassiterite, columbite, etc.) apparently may be regarded as scandium deposits. We purposely say, "apparently", because the conditions and the economy of scandium extraction from various ore types have not, as yet, been adequately studied. When we speak, in this paper, of scandium deposits, we mean first of all the deposits of tungsten, niobium, tin, zircon, rare earths, beryllium, and uranium. Thus, scandium can be produced along with other components. In this connection, a number of ore deposits of different genetic types can be identified, whose minerals have a higher scandium content.

A reservation should be made at the outset, that scandium reserves in deposits of the genetic types considered below are very scanty because of its low content. However, other natural sources of this rare element are conceivable. A considerable proportion of scandium is dispersed in ultrabasic and basic rocks, whereas the Sc_2O_3 in pyroxenes and amphiboles reaches 0.01%.

On the basis of the material gathered and analyzed by the I. M. G. R. E., Academy of Sciences U. S. S. R., scandium-carrying ore deposits can be classified, according to the accepted method for useful mineral deposits, in the manner indicated in Table 1.

Most of the known scandium-bearing ore deposits belong to the pegmatite and pneumatolytic-hydrothermal types. The remaining

[1] Skandiy v mestorozhdeniyakh razlichnykh geneticheskikh tipov.

Table 1

Genetic Types of Scandium-Bearing Ore Deposits

Type of deposit	Enclosing rocks	Scandium-carrying minerals	Characteristic paragenesis	Locality
		A. Endogenetic		
I. Pegmatite type:				
1. Platioclase-microcline-biotite with rare earth-minerals (Type II of granite pegmatites, after A. Ye. Fersman)	Granites, granite-gneisses, gabbro, amphibolites.	Thortveitite, obruchevite, wiikite, orthite, cyrtolite, chlopinite, fergusonite, biotite, muscovite, garnet.	Quartz, platioclase, microcline, biotite.	Norway – Iveland; Madagascar – Befanamo; Sweden – Ytterbi; U. S. S. R.
2. Albite-spodumene (Type V of granite pegmatites, after A. Ye. Fersman)	Granite (endocontact portion) and assorted rocks of the intrusives metamorphic and magmatic)	Cassiterite, tourmaline, garnet.	Microcline, quartz, muscovite, albite, tourmaline (black).	U. S. S. R.
II. Pneumatolytic-hydrothermal type:				
1. Deposits in albitized granites.	Granites.	Columbite, malacon.	Quartz, albite, microcline.	U. S. S. R.
2. Greisen and greisen-accompanied quartz-vein deposits.	Granites, granite-porphyries and the enclosing aluminum silicate rocks.	Wolframite, cassiterite, beryl, muscovite, brannerite, zinnwaldite.	Quartz, muscovite, topaz, fluorite, tourmaline.	U. S. S. R.; East Germany-Zinnwald, Sadisdorf.
3. Skarn deposits.	Limestones (zone of granite contact)	Ferrimuscovite, muscovite, etc.	Fluorite, magnetite, vesuvianite.	U. S. S. R.
4. Carbonatite deposits.	Ultrabasic and alkaline rocks.	Baddeleyite, pyroxene, olivine.	Calcite.	U. S. S. R.

Table 1 (continued)

Type of Deposit	Enclosing rocks	Scandium-carrying rocks	Characteristic paragenesis	Locality
B. Exogenetic Deposits				
I. Sedimentary type:				
1. Placer deposits.	Sands, gravels, siltstones, mixed-grain clastics, etc.	Cassiterite, wolframite, zircon, columbite, rare-earth minerals, baddeleyite, pyrochlore.	Quartz, topaz, garnet, ilmenite, rutile.	U. S. S. R.
2. Sorption sedimentary deposits.				
a) sedimentary deposits in sandstones.	Sandstones.	Rhabdophanite, hydroxides of TR.	Asbolite, pyrolusite, limonite.	U. S. S. R.
b) sedimentary deposits in clay.	Clays.	Carbonate-apatite and other phosphates.	Pyrite, montmorillonite.	U. S. S. R.

genetic types are represented usually by one, rarely two deposits. The reason appears to be the inadequate knowledge of such deposits with regard to scandium.

A characteristic feature of most endogenetic scandium-bearing deposits is their genetic connection with granites. The only apparent exception is the carbonatite type ore deposits.

Given below is a brief description of the genetic types of ore deposits with a higher concentration of scandium.

A. ENDOGENETIC DEPOSITS

I. Pegmatite Type

Scandium-bearing ore deposits of the pegmatite type are relatively widespread. Genetically, they are related to granite intrusions (from the Archaean to Hercynian), made up mostly of normal biotite-microcline granites. Scandium is rare in pegmatites related to alkaline granites.

The data on hand establish that scandium is accumulated in two types of granite pegmatites: a) plagioclase-microcline-biotite with rare-earth minerals (type II, after A. Ye. Fersman); and b) albite-spodumene (type V, after A. Ye. Fersman).

The latter is clearly subordinate: scandium occurs here very rarely, and its content in scandium-bearing minerals is lower than in minerals of the type II pegmatites. Consequently, plagioclase-microcline-biotite pegmatites with rare-earth minerals (type II) are the best scandium prospects.

Most scandium-bearing granite pegmatites of type II were formed under platform conditions, which suggests a considerable depth of the process. One of the critical factors in the scandium-bearing capacity of the province as a whole probably was the basic nature of the enclosing rock complex. Instances of pegmatite fields of Karelia, Norway, and Sweden confirm this assumption.

Pegmatite bodies with minerals carrying a higher content of scandium are mostly veinlike. The length of the veins is not more than a few hundred meters, with a maximum width as much as a few tens of meters.

The mineral composition of scandium-bearing granite pegmatites is as follows: 1) principal minerals -- quartz, plagioclase, microcline, biotite, muscovite, less common albite; 2) secondary minerals -- garnet,

tourmaline, topaz, beryl, gadolinite, orthite, thortveitite, zircon, fergusonite, wiikite, titanite, euxenite, chlopinite, ilmenorutile, ilmenite, magnetite, uraninite, thorite, monazite, xenotime, cyrtolite, pyrite, chalcopyrite, molybdenite, etc.

Scandium is accumulated in orthite, fergusonite, chlopinite, euxenite, samarskite, obruchevite, thorite, cyrtolite, wiikite, and certain other minerals (from 0.01 to 1.00% Sc_2O_3). In addition, associated with granite pegmatites are the rare findings of a scandium mineral proper: thortveitite (Norway; Madagascar).

A characteristic feature of pegmatite veins with scandium-bearing minerals is the presence of plagioclase and commonly of biotite. In the scandium-bearing pegmatites of Karelia and Norway, plagioclase is one of the principle vein minerals.

Pegmatite bodies with scandium-bearing minerals are differentiated and have, as a rule, a zonal structure. Generally speaking, the outer zone of quartz-oligoclase pegmatite changes toward the central part of the body, to a quartz-microcline block pegmatite surrounding a quartz core. Accumulations of biotite occur at the boundary of the block pegmatite with the core. Biotite also occurs in the outer zone.

As an instance, the Unneland (Norway) pegmatite body -- where thortveitite was first found -- exhibits a well-defined zonation. The contact zone is represented by graphic-granite pegmatite (oligoclase); the intermediate zone is represented by microcline and oligoclase blocks, with the space between filled with quartz. The central part is occupied by a quartz core. Thortveitite occurs in an intermediate zone between the graphic granite and the blocks, in association with euxenite, ilmenorutile, monazite, beryl, and biotite [9, 10].

The scandium-bearing pegmatites of south Karelia are also zoned. The most common zonation is as follows (from periphery to center): 1) a quartz-plagioclase-microcline, coarse-grained zone; 2) a microcline-perthite-block zone; 3) a quartz core. The scandium-carrying minerals (obruchevite, euxenite, etc.) are associated with a flesh-red microcline-perthite.

It should be noted that some of the scandium-carrying pegmatites contain albite pockets and albitized zones usually associated with rare-earth minerals, commonly scandium-bearing.

An instance of that is a pegmatite vein in the Alakurtti district, north Karelia, described by A.P. Kalita [7]. The following zones are observed, from the fahlbands to the center: 1) quartz-microcline-plagioclase; 2) quartz-microcline, with a graphic-granite texture; 3) microcline-quartz core with a block structure. In addition, there are replacement zones and isolated segments, made up of albite and muscovite. The scandium-bearing minerals are associated chiefly with the albite and muscovite replacement complexes located between the quartz-microcline zone and the microcline-quartz core.

For paragenetic features of scandium-bearing pegmatites of type II, the emphasis should be put on the part of rare earth elements (orthite, obruchevite, etc.), iron (biotite, magnetite), and fluorine (topaz, fluorite). Some of the scandium-bearing pegmatites show a fairly well-developed albitization associated with orthite, obruchevite, and certain other scandium-bearing minerals.

As noted above, scandium has rarely been observed in minerals from pegmatites of other types. At the present time, the presence of scandium has been established in cassiterite and columbite from pegmatites of the sodium-lithium type V (eastern Sayans; the Borshchevochnyy Range, trans-Baikal region). It appears that granite pegmatites of all types save II are unfavorable for the scandium accumulation. Our study of a considerable number of cassiterite samples from a number of pegmatite ore deposits of the sodium-lithium type failed to detect the presence of scandium.

Scandium-carrying pegmatites are usually located in the granite-emplacing rock contact zone, in both the granite massifs and in the overyling rocks.

According to V.M. Goldschmidt [6], scandium is accumulated in pegmatites as a result of assimilation of the surrounding gabbros or amphibolites by the mother melt. However, this interesting problem of the source of scandium in pegmatites requires a special study.

In conclusion, it should be emphasized that scandium-carrying pegmatite bodies are of a comparatively small size, with the scandium-bearing minerals in them, including thortveitite, present in very small quantities. Therefore, pegmatites as a possible scandium source are of an unquestionably slight significance. Only the considerable bulk of pegmatite bodies and a multiple exploitation of the ore can justify the use of pegmatite ore deposits, in isolated instances, as a source of scandium as a byproduct.

II. Pneumatolytic-Hydrothermal Type

1. Ore Deposits in Albitized Granites

The known ore deposits of this type are associated exclusively with silicic rocks, primarily with strongly albitized granites.

The higher Sc_2O_3 content established in columbite and malacon attains 0.04 to 0.07%. The mineralized bodies occur either in layers or in stocks, and are of a considerable size. The mineral composition of albitized granites is as follows: principal and secondary minerals -- quartz, albite, microcline, biotite, and muscovite; the accessory -- magnetite, columbite, malacon, tourmaline, chlorite, calcite, and fluorite. The segments nearest to the roof are the most enriched in columbite and malacon.

2. Greisen and Quartz-Greisen Deposits

Scandium-bearing ore deposits of a pneumatolytic-hydrothermal origin, particularly of the greisen type, are fairly widespread (Kazakhstan; trans-Baikal region; the northeast of the U.S.S.R.). Their main scandium carriers are: wolframite (as much as 0.2% Sc_2O_3), cassiterite (as much as 0.2%), beryl (as much as 0.07%) and micas (as much as 0.05% Sc_2O_3). The greisen deposits with scandium are genetically related to intrusions of an acid magma. A study of the rare metal deposits of Kazakhstan and eastern Trans-Baikalia has shown that greisen bodies containing scandium-bearing wolframites and cassiterites occur chiefly in the mother granite and are less common in the overlying rocks. The scandium-carrying ore bodies of this type are characterized by their complex structure. They are made up of the greisen proper, formed in a metasomatic alteration of the enclosing rocks (usually granites), and the veins filled with a high-temperature quartz as the principal vein mineral. The ore bodies are generally represented by two varieties: 1) veinlike bodies, as much as 2 km long and several tens of meters wide, and 2) stocks, with an area of not more than a few square meters, as a rule.

Principal minerals of the scandium-bearing greisens are quartz, muscovite, topaz, fluorite, and tourmaline. The different ratios of these minerals make possible the designation of several zones. The best developed among them are the quartz, quartz-muscovite, and quartz-topaz greisen zones. Among the most characteristic features of the mineral composition of scandium-bearing greisens are: the persistent predominance of quartz; the essential part of fluorine minerals -- topaz and fluorite; the considerable role of beryl; and the presence of wolframite or cassiterite among the ore minerals. A study of rare-metal ore deposits in the Soviet Union and of some of the foreign greisen deposits (Zinnwald and Sadisdorf in Germany; 6, 11, 12) has shown that scandium is accumulated in wolframite, cassiterite, beryl, and micas usually only when they are associated with topaz and to a smaller extent with fluorite.

Scandium-bearing wolframites and cassiterites occur in both the filled-up and the replacement bocies [1]. In filled-up quartz veins, these minerals occur either in isolated crystals, commonly fairly large, or else in accumulations of such crystals. In greisens, wolframite and cassiterite occur in a dispersion of small crystals. The scandium content is about the same in wolframite and cassiterite from different parts (greisens and filled-up veins) of the same ore body (as much as 0.1% Sc_2O_3).

Rare-metal greisen deposits are characterized by an even distribution of scandium in wolframite and cassiterite.

3. Skarn Deposits

Scandium-bearing skarn deposits are the least common among the genetic types. A higher scandium content, as much as 0.1% Sc_2O_3, has been noted for ferrimuscovite and less commonly for muscovite and other minerals (after A.P. Zasedatelev).

Scandium-bearing skarns, developed along the contact with limestones, form a series of lenticular bodies, with both sharp and gradual contacts. The bulk of scandium-carrying minerals is associated with mica-fluorite-magnetite skarns with chrysoberyl. Such skarns are characterized by fine-banded texture brought about by an alternation of dark magnetite and hematite bands, and light-colored ones formed by fluorite, mica, and chrysoberyl.

It must be added that this type of deposit has not been adequately studied with relation to scandium, and the scandium content in it calls for a refinement. Nevertheless, the sizable extent of skarn deposits and their relatively high Sc_2O_3 content puts them among the scandium prospects.

4. Carbonatite Ore Deposits

Carbonatite ore deposits are fairly common (Africa, Brazil, U.S.A., Norway, U.S.S.R.), and they contain important rare-metal minerals such as pyrochlore, monazite, and baddeleyite. A higher scandium content has been determined for baddeleyite (as much as 0.07% Sc_2O_3) and less commonly for pyrochlore (about 0.05%).

Two main types have been recognized among these deposits: 1) columnar bodies of carbonatites, associated with granite-gneisses and granites; and 2) carbonate bodies associated with ultrabasic to alkaline massifs, according to L. S. Borodin [2]. Rare-metal mineralization has been observed in both types.

The presence of scandium has been established in baddeleyite (as much as 0.07% Sc_2O_3) and pyrochlore (about 0.05%), from carbonatite ore deposits of the second type. Carbonatite bodies with an area as much as 8 km^2 have been traced to a depth of several hundred meters.

B. EXOGENETIC ORE DEPOSITS

I. Sedimentary Type

1. Placer Deposits

In the process of hypergenesis, scandium from cassiterite, xenotime, zircon, garnet, wolframite, baddeleyite, pyrochlore, and certain other minerals, can be accumulated in placers of these minerals. The data on the scandium content in mineral placers are very scant for the time being. Still, the higher scandium content in the above-named minerals from outcrops of their ores suggests a possible future discovery of scandium placers.

Of special interest in this respect are placers genetically related to granites (columbite, zircon); greisens (cassiterite, wolframite); carbonates (baddeleyite, pyrochlore); and pegmatites (xenotime, orthite, etc.).

2. Sorption Sedimentary Ore Deposits

a) Sedimentary ore deposits in sandstones. Higher concentrations of scandium have been observed in limonite-pyrolusite formations with phosphate impurities. The clastic fraction of mineralized rocks is represented by quartz, ilmenite, rutile, and tourmaline; the authigenic material -- by asbolite, pyrolusite, limonite, hydroxides of rare earths, and rhabdophanite. Among the useful components are scandium, rare earths, and cobalt.

b) Sedimentary ore deposits in clays have been studied quite inadequately. The data on hand suggest the possibility of a concentration of scandium, rare earths, and certain other elements in phosphatized organic remains which, in places, form local accumulations in clays. The multiple character of mineralization and the considerable extent of deposits of this type make them a possible source of scandium, this despite the rather low scandium content, of an order of thousandths of one percent.

Besides the above-named genetic types, a higher scandium content, as much as about 0.5%, has been noted, in a few places, in coal ashes (according to the data of V. M. Goldschmidt, F. Ya. Saprykin, A. B. Travin, and others).

The small amount of analytic data extant precludes a comprehensive evaluation of all genetic types of ore deposits for scandium. A further study in this field undoubtedly will enlarge our knowledge of the distribution of scandium in ore deposits of different genetic types and will allow its more precise industrial estimate.

It must be emphasized, in conclusion, that the greisen type of wolframite, cassiterite, and beryl ore deposits present, as of now, the most probable source of scandium.

It is quite possible that the near-future need for scandium might be satisfied by the ore deposits of that type.

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MESOZOIC AND CENOZOIC BLOCK-FOLDED STRUCTURES OF THE NORTHERN TIEN SHAN[1]

by

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INTRODUCTORY REMARKS

The geologic literature contains diversified definitions of block-folded structures. They originally were understood as a combination of folds and faults with block formations, and they were named after their geographic locality. Thus have originated such terms as the "Yaksartsk folding" [36], "Asian orogeny" [16, 17], and others. The "Yaksartsk folding" meant large folds broken into blocks in the process of their formation, by a number of faults; the "Asian orogeny" meant provinces of "block folds," "one-sided horsts," "lopsided massifs," "positive and negative grabens," etc., all related to shallow folded structures. According to V. A. Obruchev, block-folded structures were formed in the deformation of a tightly knit (fused together) and rigid segment of the earth's crust which was broken in the process into individual blocks.

Subsequently, the block-folded structures were defined more specifically, by their several features: their relationship with faults, the time of their origin, their relationship with the basement structures, their position in the folded province, their orographic expression, etc. The geologic vocabulary was accordingly enriched with such concepts and terms as "synclinal-graben," "anticlinal horst" [1], "inherited troughs" and "superimposed troughs" [23], "secondary geosynclines" and "geanticlinal crests" [21], "subsequent geosynclinal downwarps of the second order" [2] and "subsequent depressions" [14, 15], "inland troughs" [2] and "intermontane troughs," etc.

In addition, there appeared a tendency to ascribe a purely historic meaning to the block-folded structures and to view them as a temporary expression of a special (intermediate) state of the earth's crust, which is neither a syncline nor an anticline, nor yet a platform. Of such nature are terms like "the block-folded belt stage" [9], "the semiplatform stage" [29], "the orogenic stage" [5, 34], "the parageosynclinal state" [3], and a few others.

It should be noted that Mesozoic and Cenozoic tectonics of the Tien Shan, regarded from a historical point of view, has not received an unequivocal evaluation. For the Neogene and Quaternary, the Tien Shan is supposed to be either a geosynclinal province [D. V. Nalivkin, V. A. Obruchev, also B. A. Petrushevskiy; 25] or a zone of activization, which is akin to a geosyncline in its modern aspect [3], or else the province of a peculiar structure and development, neither a platform nor a geosyncline [15, 34]. For the close of the Paleogene, N. P. Vasil'kovskiy [6] characterizes this region as a mobile platform, whereas according to S. S. Schultz [34], the Tien Shan of that period was neither a platform nor a geosyncline but rather a comparatively slightly mobile province.

As understood in this paper, block-folded structures are a complex of peculiar deformations having originated under the conditions of a mosaic of differential movements of the earth's crust, in the interaction of rigid faulted blocks and the more plastic sedimentary mantle, and expressed chiefly in regular combinations of folds and faults. It becomes clear that, in the northern Tien Shan, the block-folded structures existed as such for a long time, in the Mosozoic and Cenozoic, and had emerged in one form or another as early as the upper Paleozoic.

I. THE MAIN VARIETIES OF BLOCK-FOLDED STRUCTURES

Along with Mesozoic and Cenozoic deposits Paleozoic deposits, separated from the Mesozoic by an erosional break, participate in the building of Mesozoic and Cenozoic structures of the northern Tien Shan. An important part in the Paleozoic morphology belongs

[1] O mezokaynozoyskikh skladchato-glybovykh strukturakh severnogo Tyan'-Shanya.

to faults which are especially widespread. Appearing simultaneously, faults either circumscribe the folds or else are located within them. All this gives to the Mesozoic and Cenozoic structures a peculiar block-folded aspect and has been a recurrent reason for their differentiation into assorted types, specifically as a combination of folds and faults.

Among minor tectonic forms of the northern Tien Shan, extending as much as 30 km in length, various authors have recognized the following:

1. Forms with sharply defined breaks in the Paleozoic basement: grabens and horsts, monoclines, one-sided grabens and horsts, faulted troughs, etc. They are usually regarded as complications in folds of a large curvature radius.

2. Forms in which the Paleozoic basement faults are combined with folds in the Mesozoic and Cenozoic sedimentary mantle: structures of a mixed horst-anticlinal and graben synclinal aspect, escalator folds of D. I. Mushketov, block brachifolds of V. I. Popov, scar folds of D. P. Rezvyy, and flexure folds of A. I. Suvorov.

3. Forms where the faults are not exposed but are traced at depth from indirect evidence: chiefly discontinuous uplifts and brachianticlines with gently dipping limbs. Their origin has been interpreted in different ways, for different instances; with the reservation, however, that they are not typical folds (B. A. Petrushevskiy, O. S. Vyalov, and others).

4. Supratenuous folds consisting of a Paleozoic core and a Mesozoic and Cenozoic mantle. Here, the basement faults may be absent; instead, there are joints and bed-slip faults within the Mesozoic and Cenozoic. The bed-slip faults induce a supplementary folding of the S. S. Schultz mantle type, the autonomous folds of N. M. Sinitsyn, drag folds of A. I. Suvorov, and in part the pseudofolds of the petroleum geologists.

Many of these forms developed during the deposition of Mesozoic and Cenozoic sediments and have been named co-sedimentary structures [34]. Some of them, as for instance the central graben of the Angren trough and the Karagunday supratenuous fold, have been expressed in the tectonic relief from the Jurassic on; some others, as the Bayastan horst-anticlinal uplift, are Cretaceous; still others (Karaunkur, Sumsar) are Paleogene and younger. Some younger structures in isolated localities originated after the accumulation of the bulk of Mesozoic and Cenozoic deposits.

The distribution of minor block-folded structures of the northern Tien Shan follows a definite pattern. Thus, structures of the first group are usually associated with zones of major uplifts (called mega-anticlines) extending over tens to a few hundreds of kilometers, whereas structures of the third group gravitate toward the central parts of major troughs (megasynclines).

Most structures of groups two and four are distributed throughout the transition zones from uplifts to troughs, with some of them -- as for instance, the autonomous folds -- occurring in deep and narrow downwarps associated with faults.

These larger structures, too, represent folded forms combining both folds and faults on a larger scale (Fig. 1), such as the Kuraminsk-Chatkal'skiy and Turkestan-Alai uplifts and the Fergana and Issyk-Kul' troughs. They are known to have existed in the present state throughout the entire Mesozoic and Cenozoic. Their presence appears to have stimulated a continual emergence of minor block-folded structure of the same type and within the same areas during the Mesozoic and Cenozoic.

In some zones, these minor block-folded structures produce paragenetic associations, which may differentiate them from each other. For instance, the author discovered three zones of different block-folded structures, on the periphery of the Fergana trough [30]. The foothills of the Kuraminskiy and Chatkal'skiy Ranges, in the first tectonic zone, are the area of the widest distribution of simple flexure folds and of very gentle uplifts all of which result from faulting in the Paleozoic basement. They are locally accompanied by minor folds (in down-throw sides of some faults and in salt-bed areas); however, these disturbances are of no particular importance. In the Fergana Range foothills, in another tectonic zone, the most important are supratenuous faults and the superimposed drag folds of several orders. The supratenuous folds most commonly have the form of a "structural nose." At times they are domelike with a core of Paleozoic stumps of the Fergana Range, usually flexed as a whole but locally shattered or presenting the features of pre-Mesozoic relief of diverse origin. In the foothills of the Turkestan and Alai Ranges, in the third tectonic zone, Mesozoic and Cenozoic structures are represented chiefly by elongated flexure (scar) folds and by larger, broad uplifts of the horst-anticlinal type, with highly elevated Paleozoic cores and complicated by numerous drag folds in Mesozoic and Cenozoic deposits. In their general form, these structures have been named complex flexure folds.

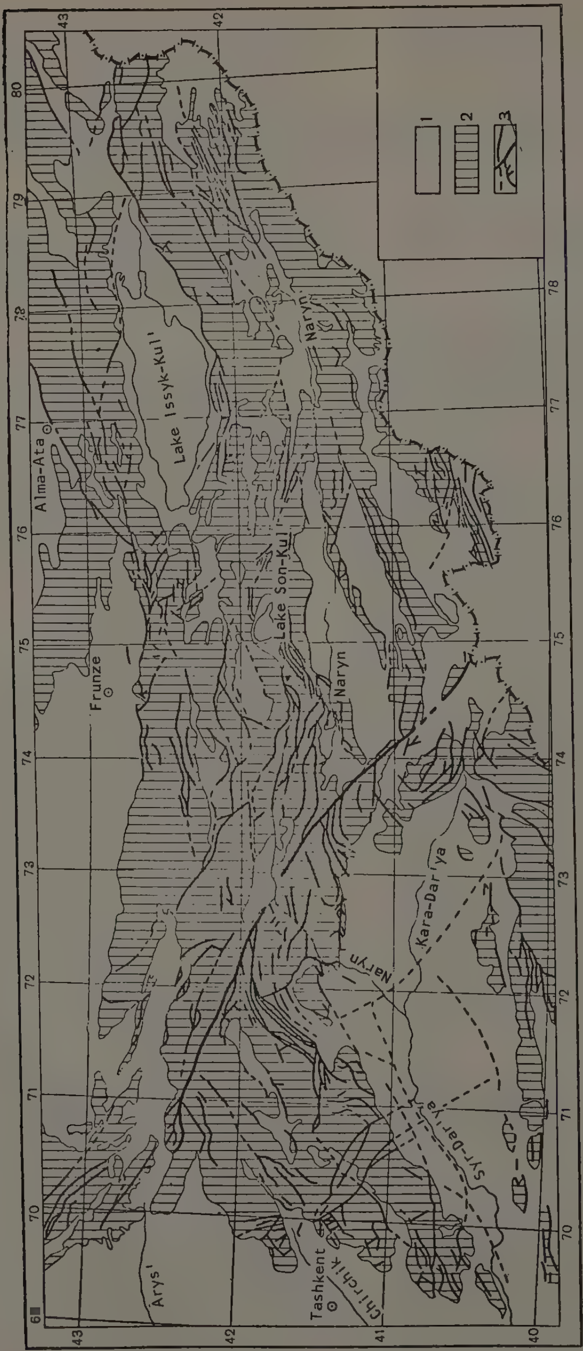

FIGURE 1. A structural map of northern Tien Shan.

1 -- Mesozoic and Cenozoic; 2 -- Paleozoic; 3 -- faults.

Interesting varieties of the block-folded structures can be seen in study of the tectonic map of northern Tien Shan. As shown in Fig. 1, it is marked by several structural trends. This important fact was noted by V.N. Weber and F.N. Chernyshev, as well as in more recent works. It was especially emphasized in the paper by K.N. Kravchenko and L.N. Smirnov [11].

It has become clear, finally, that the Chatkal'skiy (northeastern) and Karatau (northwestern) structural trends prevail in the west of the Tien Shan, whereas the Nan'shan' (west-northwest) and Altyntag (east-northeast) trends prevail in the east, beyond the Talas-Fergana fault. Correspondingly, a rectangular network of structural elements has been formed in the west, with an oblique structural network formed in the east.

The presence of several trends of the structural elements (fault zones, anticlinal and synclinal structures, structural-facies zones, etc.) strongly affected the areal outlines of many of the largest Mesozoic and Cenozoic troughs and uplifts.

Forms with wedgelike and sharp-angular terminals are overwhelmingly predominant among major structures of the eastern part of northern Tien Shan where the oblique network is present. Such are the Issyk-Kul', Naryn, Sonkul', Atbashi, Chuya, and other troughs and the adjacent uplifts. In the western part, with a rectangular network, the major forms commonly exhibit rectangular boundaries and terminal junctions of individual structural elements.

As an example, there are the Fergana and Nanay troughs whose northeastern and northwestern sides form right angles; and the Kuraminsk-Chatkal'skiy uplift trending at a nearly right angle to the Talas-Alatau and Kara-tau structures.

The tectonic layout of the Tien Shan has long been explained by purely tectonic fingering-out (virgation). However, A.V. Peyve [20] has long since shown that some of these fingers in the province under study are made up of quite unrelated elements, where the southwestern branches (such as the Kuraminskiy--Chatkal'skiy are related neither by its geologic history nor tectonically, with the leading deep structures of the same northwesterly trend. In his opinion, such structural relationships can hardly be called virgation, in the accepted meaning of this term.

It appears that it is more proper to

Table 1

Block-folded structures

Rectangularly intersecting structures		Obliquely intersecting structures	
Mega-uplifts	Intra-megatrough structures	Structures of transition zones from meta-uplifts to mega-troughs	Tectonic nodes
Horsts, grabens, noses, one-sided horsts and grabens, suprafault troughs	Very gentle brachi-anticlines, flexures uplifts, typical folds	Horst-anticlines, graben-synclines, escalator folds, block brachisynclines, scar folds, flexure folds, drag folds, monoclines	Domes, radial uplifts

assume an intersection of different tectonic trends in explaining the tectonic layout. This is suggested first of all by the above-mentioned areal outline of major troughs and uplifts. This is also suggested by the form and position of other structures originating at the intersections. In some instances, they are comes, such as the Aldyyar and Namazdek, in the southeastern Fergana province, the intersection site of the Fergana and Alai foothill structures. In other instances, they are what may be called "radial uplifts," presenting complex and intensively folded tectonic nodes, with linear structural elements radiating from them in all directions. One of such "radial uplifts" is a focal area west of the Issyk-Kul' Lake, where the block-folded Kungey-Alatau, Terskey-Alatau, Kirghiz Range, and Kendyktas Mountains, come together and cross each other in their respective west-northwest and east-northeast trends. This area separates the Issyk-Kul' and Chuya troughs and is marked by post-Jurassic volcanism (in several places, according to B. A. Fedorovich and V. V. Shumov). Here, too, as shown in the V. N. Krestnikov [12] map of recent movements, are located the epicenters of some 9-point earthquakes.

On the basis of what had been said above, the block-folded structure of northern Tien Shan can be differentiated as shown in Table 1.

This differentiation outline is interesting in two respects: the sharply defined zonation of the several block-folded structures or of some of their groups, and a wide participation of assorted joints and faults, many of the latter being the boundaries of both the individual types of block-folded structures and their zones.

II. TYPES OF MESOZOIC AND CENOZOIC SEDIMENTARY SECTIONS IN BLOCK-FOLDED STRUCTURES

The morphological diversity of Mesozoic and Cenozoic block-folded structures in northern Tien Shan is explained by a number of causes. Much of it is undoubtedly the result of the mechanism of their formation, the direction of stress, the general conditions of folding, etc. We dealt with these topics, to some extent, in our 1954 field work in Fergana. Their most comprehensive treatment is found in the latest report by V. Ye. Khain [32] which contains a classification of folds in the earth's sedimentary mantle as a whole, including the block-folded structures of central Asia.

Equally important in the formation of structures in the area under study are lithogenetic factors, such as the material composition of the deformed Mesozoic and Cenozoic rocks, their thickness, stratification, etc., all of which has been emphasized to various extents in works of V. I. Popov, O. A. Ryzhkov, S. S. Schultz, Ye. I. Zubtsov, and some other geologists. Thus in Fergana, O. A. Ryzhkov established, from the rate of shortening of the Mesozoic and Cenozoic section, the presence of brachianticlines with stratigraphic sections not truncated by an epigenetic denudation (uniaxial), and of brachianticlines with sections so shortened (biaxial and multiaxial) [27, 28].

The zonal distribution of Mesozoic and Cenozoic block-folded structures of northern Tien Shan, mentioned in the preceding chapter, appears to have been determined by the totality of factors active in the course of long periods of time. Their length is suggested, first of all, by the character of the Mesozoic and Cenozoic section greatly modified from one tectonic zone to another (Fig. 2).

In the block-folded zone with wedgelike and acute-angular terminals, northeast of the Talas-Fergana fault zone, the Mesozoic and Cenozoic section consists of two formations: Jurassic coal measures and Cretaceous and Cenozoic molasse. The first is represented by alternating motley arenaceous and argillaceous deposits with beds of carbonaceous shales, coals, and conglomerates, a total of about 500 m in the deepest troughs such as the Issyk-Kul' [34]. The second is made up of irregularly stratified conglomerates, gravels, sandstones, and subordinate shales locally with carbonate or halogen intercalations; also basalt layers. By its color, the molasse bed is subdivided into three formations: red, pale brown, and gray. Its overall thickness varies from 0 to 4000 m, with the maximum observed in the southeastern part of the Issyk-Kul' trough [24].

Southwest of the Talas-Fergana fault, throughout the area of rectangular terminal junctions of the major block-folded structures, the Mesozoic and Cenozoic section is incomparably fuller and substantially different. For instance, the composite post-Paleozoic section in the Fergana trough is as follows: Upper Triassic and Jurassic coal measures, a Cretaceous formation of fine-grained molasse, a Cretaceous carbonate-argillaceous sequence, a Cretaceous and Paleogene gypsiferous sequence, a Paleogene carbonate-argillaceous sequence, and the Neogene-Quaternary halogen-molasse and molasse formations. The Mesozoic and Cenozoic section in the middle valley of the Angren River (Kuraminskiy-Chatkal'skiy uplift) comprises Jurassic coal measures, a Cretaceous and Paleogene molasse formation, a Paleogene clastic-carbonate-argillaceous sequence, and a Neo-

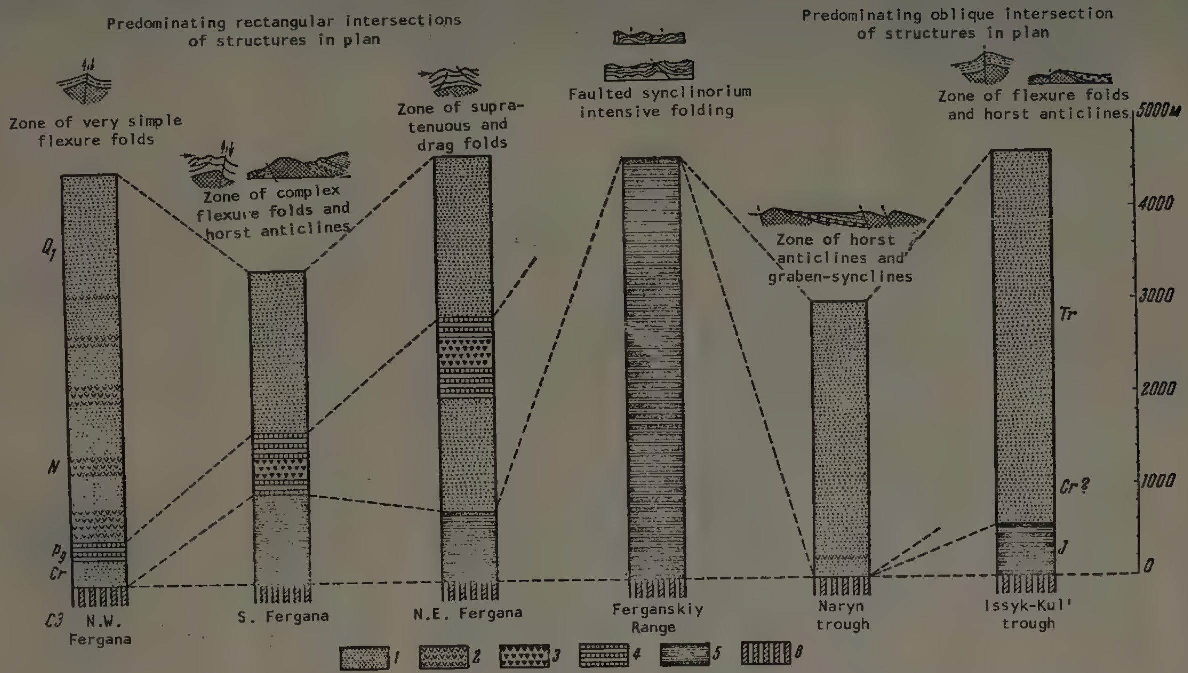

FIGURE 2. Correlative cross section of formations and types of tectonic structures for main Tien Shan troughs.

1 -- Molasse; 2 -- Halogen-molasse; 3 -- Gypsiferous sequence; 4 -- Carbonate-argillaceous sequence; 5 -- Coal measures; 6 -- Paleozoic.

gene-Quaternary molasse formation. The Mesozoic and Cenozoic is 3 to 4.5 km thick in the Fergana foothills, and increases toward its central part. The maximum thickness in Angren is 700 to 1000 m.

The different structural setup of the two zones, northeast and northwest of the Talas-Fergana fault, together with the different configuration in their megastructures, is obviously the result of the difference in their geologic development during the Mesozoic and Cenozoic. The zone northeast of the Talas-Fergana fault has been marked by its persistent uplift tendency, which has led to an elevated metamorphic basement and to its splitting along the oblique network of faults.

The three main tectonic zones of the Fergana foothills, in turn, differ among themselves in the character of their sections, which is seen in Table 2.

These sections are different in their completeness, overall thickness, the volume and age of individual members (sequences, formations, beds), their facies composition, etc. The literature contains references on this subject, although somewhat slanted, because of the understandable desire for a unified stratigraphy for the Mesozoic and Cenozoic. Specifically, A. M. Gabril'yan [7] emphasized the correlation difficulties in many instances, between the Cretaceous and Paleogene deposits of the south and east Fergana, whereas the Cretaceous of northern Fergana could not be correlated at all with the rest of the Fergana depression. He believes that the east-Fergana and Kuraminskiy area are zones essentially different in their tectonics from the remainder of the province.

The origin of the above-named principal block-folded zones in the Fergana depression foothills is apparently the result of the difference in their Mesozoic and Cenozoic tectonic conditions. This is confirmed by the corresponding types of Mesozoic and Cenozoic sections.

But that is not all. As shown in the table of Mesozoic and Cenozoic sections, in the southern and eastern zones of Fergana as compared with its northwestern zone, the deposits are markedly heterogeneous. Drag folds are widely distributed among Mesozoic and Cenozoic folds, both in the south and in the east. These folds, as we have pointed out before, originated from horizontal stresses and slips and thrusts which were more or less intensive in the southern and eastern regions. The main, direct prerequisite for their formation, however, was the lithologic features of the structure involving the local Mesozoic and Cenozoic beds; the heterogeneity of their composition being the foremost factor. It is not an accident that the main displacement surfaces in the bed-slip movement within the Mesozoic and Cenozoic were the boundaries between the most lithologically dissimilar layers.

The direct relationship between the lithology of the deformed deposits and the morphologic aspect of the end tectonic forms stand out even better in the east-Fergana coal basin. This basin presents a narrow and deep downwarp filled with Jurassic coal-bearing deposits: sandstones, siltstones, shales, and conglomerates, all carrying coal beds. This downwarp runs along the Talas-Fergana fault and represents, for this reason, special structure types which have been named the near-fault downwarps [25].

The Jurassic coal measures of the east Fergana basin are subdivided into five formations. According to Ye. I. Zubtsov [8] and G. L. Bel'govskiy [4], they attain a maximum thickness of 5 km in the eastern and southeastern parts of the basin. Going southwest and west, this thickness decreases to 1200 to 1500 km as established by Ye. I. Zubtsov, by wedging-out from bottom to top, with the formation boundaries shifting gradually. Two types of Jurassic coal measures have been recognized in the trough: the "central," immediately adjacent the Talas-Fergana fault zone; and the peripheral, along the western boundaries of the basin. The first is marked by the maximum thickness of the coal-bearing sequence, a higher metamorphism of coal, a larger number of beds, a more regular stratification, a finer arenaceous and argillaceous composition of the principal rocks, and a higher degree of their metamorphism. Igneous activity is widespread in this segment in the form of veins. The second type is marked by a considerably smaller thickness, by a large number of erosional and unconformable contacts, irregular and cross bedding, coarser facies composition of the sediments, and a lower degree of their metamorphism.

The coal-bearing formations are gathered into numerous folds and are cut by a number of faults, chiefly of a reverse type. According to some authors, broad and gentle folds of the "supratenuous" or transitional "escalator" type prevail in the western peripheral section, where the dips are nearly flat, locally. In the part of the basin adjacent to the fault, where the section is thicker and more complete, the deformation is sharply intensified, with the appearance of strongly compressed to isoclinal "autonomous" folds. In the upper course of the Kara-Tyube River, deformations are expressed, according to V. N. Ognev [18], in a complex fan of steep folds. They trend from southeast to north-

Table 2

Northwestern Fergana; zone of very simple flexure folds	Northeastern and east Fergana; zone of supratenuous and drag folds	South Fergana; zone of complex flexure folds
VI. Halogen-molasse sequence: salt and gypsiferous formations of Supe-Tau; argillaceous gypsiferous deposits of Chust-Papa and the overlying pale straw-colored-to-brown arenaceous and argillaceous and sandy pebble deposits (up to and including the Quaternary); thickness 4 km.	VI. Shallow and deep water clastic molasse: red to pale pink, brown and gray formations of the Massagetian, Bactrian, and Sokh stages; 1.5 to 2 km.	VI. Fine- to coarse-grained brown to gray molasse: arenaceous and calcareous mudstones and conglomerates of the Bactrian and Sokh stages; 1.5 to 2 km.
V. Carbonate-argillates: organogenic limestones, clays, sands, locally conglomerates of the Susak-Sumsar Paleogene stage, and raspberry-red clays of the Massagetian stage; 200 m.	V. Upper carbonate-argillaceous sequence: organogenic limestones and clays of the Alai-Sumsar Paleogene stages, changing upward to raspberry-red Massagetian clays; 200 m.	V. Upper carbonate-argillaceous sequence: organogenic carbonate and clays of the Alai-Sumsar Paleogene stage; red clays of the Massagetian stage; predominance of clastic material in the south; 300 m.
—	IV. Upper Cretaceous motley calcareous arenaceous argillaceous gypsiferous sequence: dark red gypsiferous clays of the epi-Radiolite formation; carbonate-argillaceous gypsiferous deposits of the Suzak and Bukhara Paleogene, with clastics predominating in the northwest; 360 m.	IV. Gypsiferous sequence: red to motley sands, sandstones, mudstones, gypsum and dolomites; the Goznau gypsum formation; Paleogene arenaceous and argillaceous deposits interbedded with gypsum and dolomite beds (Bukhara and Suzak stages); 200 m.
—	III. Lower carbonate-argillaceous sequence: thick oyster beds with thin intercalation of green clays (Exogyra formation); green to red clays changing upward to red sands (Yalovach formation), with clastics predominating in the northwest; 280 m.	III. Lower carbonate-argillaceous sequence: marly shales of the Muya Lower Cretaceous formation; white to rosy dolomitic limestones and dolomites of the Lyakan formation; red marly shales of the Kizyl-Pilyal formation; red shales and conglomerates of the Upper Cretaceous Kalachinskaya formation; conglomerates, sandstones, marls of the Exogyra formation; 165 m.
II. A shallow clastic molasse formation: barren red sandstones and sands interbedded with conglomerates and marls of the Bukhara Cretaceous stage; 290 m. Total, 4.5 km.	II. Finely clastic molasse: red mudstones and sandstones of the Lower Cretaceous Changet series and the Upper Cretaceous Kalachinskaya formation; coarse-clastic molasse in the northwest, with a basalt bed; 1200 m.	
—	I. Coal measures of the Liassic, Dogger, and possibly Malm; conglomerates and sandstones with subordinate shales and coal beds; the latter locally form commercial deposits; 800 m. Total, 4.5 km.	I. Coal-bearing arenaceous and argillaceous deposits with Upper Triassic plant remains (as much as 640 m); sandstones and shales with beds of coal and conglomerates with a Liassic flora (as much as 800 m). Total, 3 km.

west, following the general trend of the basin. The folding is asymmetrical, as if leaning to the southwest in which direction the folds are tilted and overturned. According to Ye. I. Zubtsov [8], folds along the northeastern flank of the Fergana Range, although remaining strongly compressed, regain an upright posture or else are slightly tilted to the northeast. He defines the general aspect of the Jurassic structures as asymmetrical and fan shaped.

Depending on the distribution of facies, thicknesses, and deformations, a central (near-fault) and a peripheral structural-facies zone have been differentiated within the east-Fergana coal basin. The names of these zones symbolize, in a way, the interrelationship of the folding and lithologic factors. At the same time, this instance illustrates the effect of other factors, such as the presence of the Talas-Fergana fault whose throw has determined both the east-

Fergana trough as a whole and its structural-facies zones, along with the stresses necessary for the folding.

Finally, the elevation of the deformed Mesozoic and Cenozoic sections, relative to the more rigid Paleozoic surface should not be overlooked as an important factor affecting the morphological aspect of the Mesozoic and Cenozoic block-folded structures of the northern Tien Shan. These elevations are determined by the submergence depth of the Paleozoic surface and by the thickness of the Mesozoic and Cenozoic.

The uplift zones, as has been pointed out, are marked by structural forms connected with well-expressed basement faults: horsts and grabens, one-sided horsts and grabens, monoclines, and troughs superimposed on faults. In such zones, the Mesozoic and Cenozoic section is thinner, the formations are marked by a coarser grain and areal discontinuity. Such are the zones of the Kuraminskiy-Chatkol'skiy and Turkestan-Alai uplifts. In zones transitional from mega-uplifts to megatroughs, quite different forms are developed, such as horst-anticlines and graben-synclines, flexure and scar folds, etc. They occur in the foothills of the Issyk-Kul' and Fergana depressions, and in other regions. Finally, in zones of deep downwarps, where the Mesozoic and Cenozoic is 4 to 5 km thick and more (and is of even finer and more heterogeneous composition), "atypical" folds originate, i. e., very gentle, barely expressed at the surface, as for instance in the interior of the Fergana depression; or else, in areas under stress, there appears extremely intensive folding, with steep and compressed folds and with evidence of displacement along the bedding planes, as in the east-Fergana Basin.

Thus it appears that the zonation in the distribution of Mesozoic and Cenozoic block-folded structures according to several morphological varieties has its historical and geological prerequisites, in the northern Tien Shan. A basic condition of their origin is the contrasting movements of segments of the earth's crust, whereas their morphological appearance is determined, in each instance, by the basement relief, the lithology of the deformed rocks, and the direction of the deforming stresses.

Another significant and conspicuous fact is the importance of coarse clastics in the Mesozoic and Cenozoic section of northern Tien Shan. They are very characteristic for the molasse sequence for a considerable portion of the coal measures, and for isolated areas of development of the carbonate-argillaceous and gypsiferous intervals. It appears as though the wide development of Mesozoic and Cenozoic block-folded structures in the northern Tien Shan is accompanied by an equally wide distribution of peculiar deposits rich in coarse clastics, in its Mesozoic and Cenozoic stratigraphic section. These clastics, on the whole, can be assigned to the intermontane sedimentary group.

III. THE INHERITANCE PHENOMENA IN THE DEVELOPMENT OF MESOZOIC AND CENOZOIC BLOCK-FOLDED STRUCTURES

Many authors, including S. S. Schultz and B. A. Petrushevskiy hold the view that the Tien Shan Mesozoic and Cenozoic deformations were produced exclusively by folding, and that the movement along fault planes did not become paramount until the end of the Tertiary. In addition, there are references in the literature (A. V. Peyve, V. I. Popov, etc.) to the longevity of many major faults which had been found to be the boundaries of structural-facies zones and the corresponding flexures. This has become especially clear in recent years, after the long-developing faults of different ages had been reported in mass from Tien Shan and from other parts of the Soviet Union. From that time, the necessity to regard the tectonic forms as a combination of faults and folds, both characterized by a long inherited development, has become more and more obvious.

The general problem of tectonic inheritance, as elaborated by N. S. Shatskiy, has, in its present state, three closely connected aspects: 1) the inheritance of tectonic plan; 2) the inheritance of tectonic forms; and 3) the inheritance of tectonic movements [22]. All these aspects are readily recognized in the development of Mesozoic and Cenozoic block-folded structures of the northern Tien Shan.

In applying the term, inheritance, to the Tien Shan structures, we imply, first of all, their long duration as Mesozoic and Cenozoic structures; and second, their dependence in one way or another on the similarly block-folded structures of the Paleozoic basement.

In its structural plan, the northern Tien Shan has been differentiated, as pointed out above, into a zone of obliquely intersecting tectonic elements (northeast of the Talas-Fergana fault) and that of predominantly rectangular intersections (southwest of the fault). The first zone is marked by a network of west-northwest and east-northeast trending faults; the second, by faults trending chiefly northwest and southeast (only the largest faults). The two zones differ sharply

in the character of their Mesozoic and Cenozoic sections.

The acute-angular intersection pattern, characteristic for the Mesozoic and Cenozoic tectonics in the eastern part of northern Tien Shan, holds true for the Carboniferous as well. The work of V. G. Korolev [10], east of Lake Issyk-Kul', in the Karkara-Tekes watershed, has established the structural asymmetry for pre-Visean rocks which locally display (along faults) abrupt changes in their thickness and facies composition.

In the upper Tekes depression, for instance, the sediments are as much as 3.5 km thick, whereas they are altogether lacking in the adjacent Karkara uplift. Flysch-like calcareous arenaceous and argillaceous sediments predominate in the depression; they change to conglomerates, going toward the uplift.

V. G. Korolev has outlined several such depressions and uplifts, bounded by faults (Fig. 3). Paleozoic faults, like those of the Mesozoic and Cenozoic, trend in the same west-northwest and east-northeast directions, and that the Paleozoic tectonic structure east of Issyk-Kul' is amazingly similar to its Mesozoic and Cenozoic structure. Moreover, some of the Paleozoic faults fall in line with the Mesozoic-Cenozoic (as, for instance, with the fault separating the Issyk-Kul' trough from the eastern Kungey-Alatau uplift).

The rectangular intersection of structures, as observed southwest of the Talas-Fergana fault, also stems from the Paleozoic, being expressed in both the disposition of faulted uplifts and troughs and the distribution of sedimentary and igneous rocks and paleographic boundaries, elongated in the two intersecting directions, northeast and northwest.

Thus, judging from the maps of N. P. Vasil'kovskiy [6], middle Carboniferous extrusives in the southeastern prongs of northern Tien Shan, form a northwesterly trending zone in the Angren headwaters; this zone locally coincides with the Kumbel'-Arashan fault zone. The same northwesterly trend has the boundary of middle Carboniferous sedimentary rocks occupying the extreme southwestern reaches of the Kuraminskiy-Chatkal'skiy uplift. On the other hand, rocks of the pre-Aktash intrusive complex, between the upper and middle Carboniferous, are located in a northeast trending belt. In the upper Carboniferous, the marine deposits boundary along the southeastern slope of the Kuraminskiy Range is traceable to the northeast, whereas the Upper Cretaceous Aktash volcanics are developed in the southwestern half of the Kuraminskiy-Chatkal'skiy uplift, sharply cut off its northeastern half by the northwesterly trending Arashan regional fault.

The crosswise disposition of sedimentary and volcanic rocks in the southwestern prongs of northern Tien Shan has also been established, from isolated structural fragments, for the upper Paleozoic and Mesozoic. It was especially well expressed in the Cenozoic and in the terminal stages of development, for this area. By that time, the present uplifts of the Kuraminskiy and Chatkal'skiy Ranges, separated by the northeasterly trending Angren trough, were fully formed, along with the Kumbel' and Arashan regional faults, trending northwest and controlling the areal distribution of marine Paleogene sediments [31].

One gets the impression that block-folded structures in both the eastern and especially the western part of northern Tien Shan, trending as they do in different directions, in the upper Paleozoic, Mesozoic, and Cenozoic, are growing into each other. For this reason, we deem it proper to call them, the "implication"[2] block-folded structures, further differentiating them into rectangular and oblique implication structures. They are also likely to be widespread in other block-folded provinces. For instance, rectangular structures occur in the southeastern fringe of the Uspensk zone, central Kazakhstan; whereas oblique structures are developed in the areas of certain ancient anticlinoria with an elevated metamorphic basement (Chinghiz and possibly Ulatau).

The genealogy of the Mesozoic and Cenozoic structural plan of northern Tien Shan from an upper Paleozoic setup, and predetermined by the network of faults, appears to have been most stable, inasmuch as the intersections of one type or another have persisted here for a long time, despite the frequent vagaries of geologic events. The situation is somewhat more complicated for the other aspects of heredity, as pointed out above, which has received a more diversified expression.

Long-enduring Mesozoic and Cenozoic areal structures, and those inherited from the Paleozoic, are present in the eastern part of northern Tien Shan, alongside the stable network of faults. An instance of such an areal structure is the Issyk-Kul' trough. According to V. G. Korolev [10], its eastern part was a deposition site in the Carboniferous, separating the already uplifted Kungey-Alatau

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[2] From implicatio -- interweaving; this term is used in petrography to designate a regular intergrowth of two minerals.

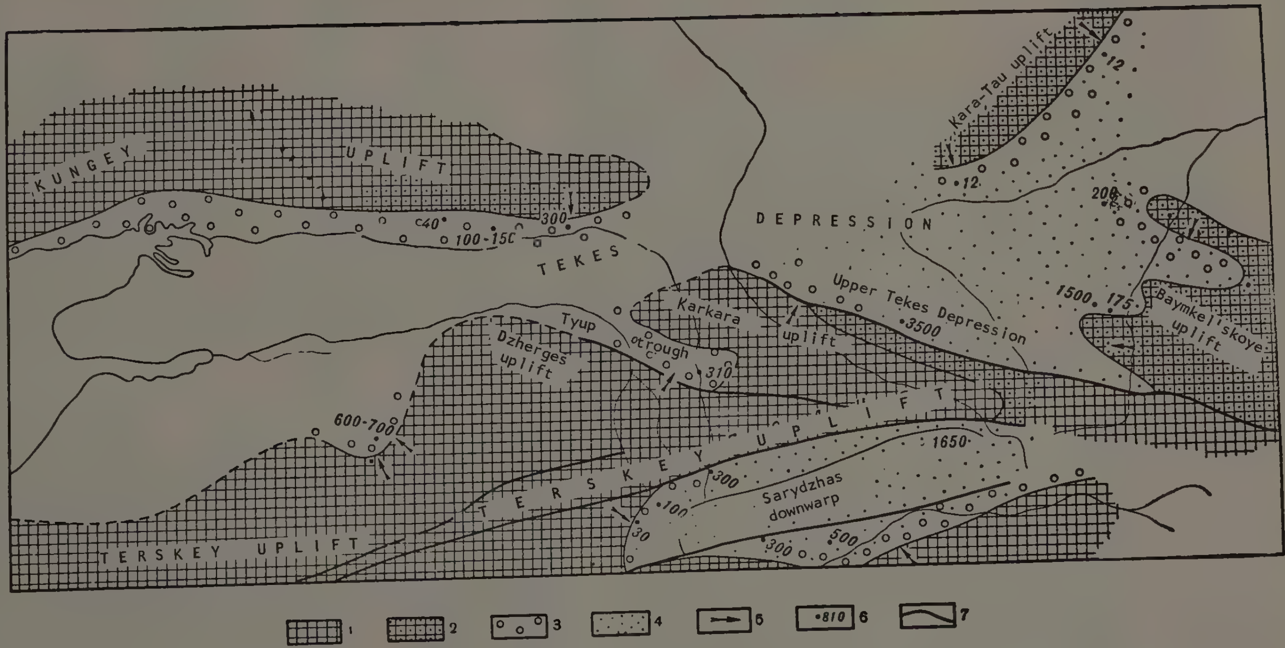

FIGURE 3. Paleotectonic map for the beginning of the upper Visean (After V.G. Korolev).

1 -- Uplifts in the pr cess of erosion; 2 -- parts of uplifts with limestones of the end of the Visean transgression; 3 -- conglomerates along the periph..ry of troughs; 4 -- arenaceous and argillaceous and calcareous arenaceous and argillaceous deposits in troughs; 5 -- direction of removal of clastic material; 6 -- thickness of section below the base of upper Visean limestones; 7 -- supposed faults.

and Terskey-Alatau Ranges. This deposition trough, as pointed out by S. S. Schultz [34], persisted into the Jurassic. In the Cretaceous and Tertiary, a thick molasse formation was deposited in the same trough.

The greatest thickness of upper Visean conglomerates was measured in the southeast of the Issyk-Kul' trough, where it reaches 600 to 700 m thick; in the north, at the Kungey uplift, it is 40 to 150 m, only locally attaining 300 m. The maximum thicknesses of Jurassic coal measures and of Cretaceous and Tertiary molasse (as much as 4.5 km) are also associated with the southeastern end of the trough. The maximum depths of the present Issyk-Kul' (702 m), too, are found near its south shore. Thus the Issyk-Kul' trough not only has been downwarping in the course of Paleozoic and Mesozoic and Cenozoic sedimentary eras, approximately within the same boundaries, but also has preserved its asymmetry.

The stability in the form of the Issyk-Kul' trough and adjacent uplifts has also been reflected on the smaller block-folded structures. The latter are similar to each other, in the Carboniferous, Mesozoic, and Cenozoic of the area: in a number of places, they are associated with faults, are marked by the simplicity of their structure, and are asymmetric. It is most probable that steacy vertical movements prevailed in the east of Tien Shan, in the upper Paleozoic, Mesozoic, and Cenozoic.

Areal forms commensurable with the Issyk-Kul' trough and having developed in the same direction, during the Paleozoic, Mesozoic and Cenozoic are scarce. To the contrary, many downwarps in that part of Tien Shan are distinguished by a very short development period, as for instance the east Fergana downwarp, along the Talas-Fergana fault, filled with Jurassic coal-bearing deposits, as much as 5 km thick, producing a lofty range since the Cretaceous. Moreover, a steady shift in its maximum downwarps, from one period to another, took place in the Mesozoic and Cenozoic [8, 27, 30]. In the Jurassic, the maximum submergence took place in the confines of the present Fergana Range; in the Cretaceous it shifted to the latter's southwestern foothills (thickness, more than 1000 m); in the Paleogene to the south edge of central Fergana (500 to 600 m thick); in the Neogene and Quaternary to the northwest of Fergana (as much as 4 km thick). On the whole the downwarps migrated from the Fergana and Turkestan-Alai Ranges to the Kuraminskiy and Chaktal'skiy. In almost all instances, they are associated with Paleozoic basement faults, as reflected in the mantle structure and demonstrated by geophysics.

It is of interest that elements of a similar regular northerly shift of troughs and uplifts, in the process of their development were recently disclosed for a considerable area of the Alai Range, by N. A. Lisitsina [13], in her study of upper Paleozoic formations (Carboniferous and Lower Permian). This suggests that such features, namely the short life of individual troughs and their methodical migration in the upper Paleozoic, were also characteristic of other regions, southwest of the Talas-Fergana fault, and that they were inherited by the Mesozoic and Cenozoic. The inheritance of forms and movements there took a somewhat different course than in the east of Tien Shan.

On the background of a methodical lateral migration of downwarps and uplifts, in individual zones, there looms, in the vertical section, a definite recurrence of certain geologic phenomena. The Talas-Fergana fault zone is associated, as has been noted above, with the deepest Jurassic downwarp containing thick (as much as 5 km) and intensively folded sediments. The same zone is associated with a deep upper Paleozoic downwarp. V. N. Ognev and A. D. Miklukho-Maklay [19] have described upper Paleozoic (chiefly upper Carboniferous) flyschlike deposits from the central and southeastern parts of the Fergana Range, as much as 6.3 km thick, and also intensively contorted into small folds. In addition, the Fergana-Range zone underwent considerable uplifts: once in the Cretaceous and Cenozoic when the present Fergana Range originated; the other time at the end of the Paleozoic and at the onset of the Mesozoic. The latter event is marked by the absence of sediments of that age in the section. Thus the Fergana-Range zone presented a highly mobile zone, in the upper Paleozoic, Mesozoic and Cenozoic events in this zone (downwarping, sedimentation, folding, uplift) was apparently inherited from a similar Paleozoic sequence. This, then, is the second form of inheritance throughout the area southwest of the Talas-Fergana fault.

Finally, features of the heterogeneous structure of certain regions, too, are inherited here. It has already been noted, for instance, that the Fergana trough exhibits three zones of block faulting, with a specific Mesozoic and Cenozoic sedimentary section deposited in each. Thus, the Fergana trough presents a complex heterogeneous Mesozoic and Cenozoic form consisting of various parts with tectonics of their own.

Turning to the structure of the Paleozoic fringe of the trough, we note that it, too, is not uniform. Extrusive rocks predominate in Paleozoic and especially the upper Paleozoic rocks throughout most of the Kuraminskiy-Chatkal'skiy uplift adjacent to the zone of

very simple flexure folds. Nothing of the kind is present in the neighboring Tien Shan regions, including the Fergana Range and south Fergana, where sedimentary facies predominate. The latter, in their turn, are not the same in the south and east of Fergana. Within the Fergana Range (which adjoins a zone of Mesozoic and Cenozoic supratenuous and drag faults) there is developed a thick zone of flyschlike upper Paleozoic deposits; in the south Fergana, on the other hand (in the fringe of Mesozoic and Cenozoic flexure folds zone), there appear in addition to the flysch, according to N. A. Lisitsina [13], carbonates and marine coarse clastic molasse, thinner than in the east.

The area of the Kuraminskiy and Chatkal'skiy Ranges, from Wenlockian time on, has been rising [26], while the provinces to the south have been downwarped. According to N. P. Vasil'kovskiy [6], this province was during the Early Devonian, the edge of a mobile Caledonian platform, south of which the Hissar-Alai geosynclinal zone maintained its downward movement. According to him, this relationship between these provinces persisted with some interruptions to the end of Early Permian. The late Paleozoic downward movement was more intensive in the east of Fergana, while several somewhat smaller troughs were formed to the south, where they were separated by uplifts and subsequently migrated from south to north.

The uplifting tendency in the Kuraminskiy-Chatkal'skiy region, and the sinking tendency (with interruptions) in the south and east Fergana persisted for a fairly long time, in the Mesozoic and Cenozoic and especially the Jurassic, Cretaceous, and Paleogene. Thus these distinctive features of structure and development of the three principal Mesozoic and Cenozoic stages of the Fergana trough, which account for its Mesozoic and Cenozoic mobility, have been inherited from the late Paleozoic.

Several aspects of heredity of Mesozoic and Cenozoic structures from the Paleozoic (whose roster is not complete, of course) bear witness to a causal relationship between the two sets. This appears to be the true cause of the zonal disposition for the variety of block-folded structures in Tien Shan. It is obvious that the Paleozoic -- Mesozoic-Cenozoic boundaries are less important than was previously thought. In any event, this problem should be re-examined. The Mesozoic, Cenozoic, and upper Paleozoic "structural stages," despite the erosional break between them, are related to each other by the community of their tectonic plan, forms, and movement, instead of differing sharply in their structure. The only difference is in the upper Paleozoic where they are enriched (in certain zones) by igneous activity and carry a better development of flyschlike rocks. However, according to N. P. Vasil'kovskiy and other geologists, the igneous activity did not end in the upper Paleozoic but persisted to the early Mesozoic and locally, even later. As to the sedimentary formations, some of them, such as the molasse, were noted not only in the Mesozoic and Cenozoic sections but in the upper Paleozoic as well. Some of the Jurassic arenaceous and argillaceous sequences (in the southeast of the Fergana Range) were mistaken for those from the upper Paleozoic.

CONCLUSION

Northern Tien Shan is an example of a broad development and clean-cut manifestation of block folding. Its Mesozoic and Cenozoic block-folded structures are differentiated into a number of morphologic varieties and form zones of the "implication" structure and development. They witnessed a long Mesozoic and Cenozoic development accompanied by the accumulation of chiefly coarse clastics in the intermontane troughs.

In the character of its Mesozoic and Cenozoic structure, Tien Shan cannot be assigned to either folded, geosynclinal, or platform conditions. Obviously, it cannot be said that the Mesozoic and Cenozoic northern Tien Shan witnessed a change from the platform to geosynclinal conditions, inasmuch as a stable consequent development of a number of Mesozoic and Cenozoic block-folded structures took place there. In accordance with the above data, northern Tien Shan can be defined as a province of a special type of structure and development, namely a block-folded geosynclinal province.

As such, this province was clearly defined as early as the upper Paleozoic. This was reflected in the formation of the corresponding tectonic forms, in the various trends of their development, and in the local deposition of some of the molasse formations (and perhaps of some others, yet unknown). The time of the initiation of the northern Tien Shan block-folded geosynclinal province is not known. It may be assumed with a fair degree of certainty that the process of its development was long and complex, and probably ran different courses in different parts of Tien Shan.

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MESOZOIC COAL MEASURES ON THE EASTERN SLOPE OF THE MALYY (LITTLE) KHINGAN RANGE AND ADJACENT PROVINCES[1]

by

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In the thirties, a study of the geologic structure of the Malyy Khingan Range and adjacent provinces of the western Amur region was made by the Far Eastern Affiliate, Academy of Sciences, U.S.S.R., and by various geologic prospecting organizations of the Far East, also by the All-Union Organization for the Settlement of the Toiling Jews in the U.S.S.R. [4, 5, 9, 10, 12, 13, 14]. More recently, a geophysical study was carried out within the Jewish Autonomous Province, by the Ministry of Geology and Conservation of Mineral Resources, U.S.S.R., and the Main Geological Administration of the former Ministry of Coal Industry, during the search for coal-bearing areas.

As a result of these efforts, geologic maps of the Malyy Khingan Range and the country east of it were drawn on a scale of 1:500,000, and larger for individual areas. In addition, stratigraphic divisions were established for Paleozoic and Mesozoic deposits, tectonic maps drawn on small scales, and the deposits of useful minerals described (iron ores, coals, cement ingredients, etc.).

This paper is a brief account of field work done by the author in 1952 in the Bol'shaya Bira Basin, commissioned by the Main Geological Administration of the former Ministry of Coal Industry U.S.S.R. (Fig. 1).

I. STRATIGRAPHY AND AGE OF THE COAL-BEARING FORMATIONS

S.V. Konstantov [5], S.I. Shkorbatov [14], S.A. Muzylev [10], and G.P. Volarovich [4] proposed the earliest stratigraphic differentiation for the Mesozoic east of the Malyy Khingan Range. This task, especially with regard to coal measures, was accomplished by these students chiefly of lithology, with very scant biostratigraphic data (Table 1). In this connection, G.P. Volarovich in his compilation of the geology of the Malyy Khingan [4], states that all Mesozoic sections, known in 1912-1935, display a meager state of knowledge, also confirming the great changes in their lithology, both vertically and laterally.

The floral assemblages of the coal measures have been considerably complemented as a result of the author's field work in the Bol'shaya Bira Basin and by the work of Khe Si-Lin' [13] in the lower Sungari Basin. This made it possible to pinpoint the age of the coal measures and to correlate them with those in the Zeya and Bureya Basins. In 1952, we found the following fossil fauna in tuffaceous sandstones and tuffites with coal beds on the left bank of Bol'shaya Bira, south of the village of Ugol'naya Sopka which lies 2 km east of Bira Station on the Amur Railroad (identified by R.Z. Genkina): Cephalotaxopsis brevifolia Font., C. acuminata Krysht. et Pryn., Cladophlebis haiburnensis L. et H., Cl. sp. ex gr., C. haiburnensis (L. et H.) Sew., Cl. sp., Cl. haiburnensis Pryn., Coniopteris sp., C. hymenophylloides Brongn., C. burejensis (Zal.) Sew., Equisetites sp. cf., E. columnaris Brongn., E. sp. Elatocladus manshurica (Jabe) Jok., Ginkgo sibirica Heer, G. arcodentata Pryn., Gleichenia sachalinensis Krysht., Phoenicopsis sp. cf., P. angustifolia Heer, Pityophyllum nordenskiöldii (Heer) Nath., Podozamites lanceolatus L. et. H., Onychiopsis elongata (Geyl.) Jok., Raphaelia tapkensis (Heer) Pryn., Scleropteris tarbagataica Pryn., Sphenopteris sp. ex gr., Coniopteris burejensis (Zal.) Sew.

The presence of these fossil plants makes it possible to assign the coal measures which contain them to the Upper Jurassic to Lower Cretaceous. These deposits are represented chiefly by tuffs, tuffaceous lavas, and tuffaceous polymictic sandstones with coal beds. By lithology (tuffaceous formations, coals) and paleobotanical characteristics, this stratigraphic complex is separated as the Birsk formation of a Lower Cretaceous age (Table 1). S.I. Shkorbatov [14] assigned the above-

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[1]Uglenosnyy mezozoy vostochnogo sklona khrebta malyy khingan i sopredel'nykh oblastey.

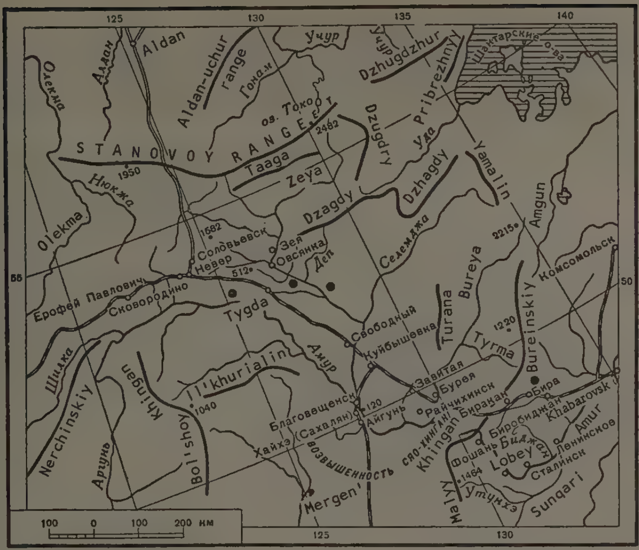

FIGURE 1. Index map of a part of the Far East and adjacent provinces of Manchuria and southeastern trans-Baikal region. Black circles mark the localities of the 1949-1952 work.

mentioned coal-bearing formations in the Ugol'naya Sopka area to the "sandstone sequence," Lower Jurassic or Triassic in age. This appears to be incorrect in the light of new data, because these deposits are found to lie higher in the Mesozoic section. This conclusion is confirmed by the above-mentioned fossil fauna assemblage, as a whole, also by the presence of Onychiopsis elongata (Geyl). Jok., usually confined to the Lower Cretaceous but also occurring in the Upper Jurassic. The same is true for Gleichenia sachalinensis Krysht. Furthermore, the entire floral assemblage from the Birsk coal measures -- consisting chiefly of fern genera Cladophlebis, Coniopteris, Sphenopteris, Onychiopsis, Gleichenia, and Raphaelia; ginkgo genera Ginkgo, Sphenobaiera, Phoenicopsis; partly of conifers and horsetails -- is similar to the floral assemblage from the Bureya coal basin coal measures, where it is assigned to the Upper Jurassic and Lower Cretaceous [15]. As a result of the recent work by V.A. Vakhrameyev and other students, it has been established that the Amur fauna (the Bureya Basin and the middle course of the Amur) essentially belongs to the Lower Cretaceous, with only the fossil plants from the base of the coal measures apparently belonging to the Upper Jurassic [7].

The coal measures in the area of Londoko Station on the Amur Railroad, 36 km west of Bira Station, are correlated by S.I. Shkorbatov [14] with the Ugol'naya Sopka coal measures. However, to assign them to Lower Jurassic or Triassic is withour foundation, because of the following fauna collected from the Londoko area coal measures in 1952, and identified by R.Z. Genkina: Anomozamites lindleyanus Schimper, Ginkgo sibirica Heer, Coniopteris maakiana (Heer) Pryn., C. hymenophylloides (Brongn.), C. obrutschewii (Krasser) Pryn., Pityophyllum nordenskiöldii (Heer), Podozamites lanceolatus L. et H., Onychiopsis mantellii Brongn., Sphenopteris naktongensis Jabe, Sphenopteris ex gr. Geoppertii Dunk., S. sp. ex. gr., Coniopteris burejensis (Zal.) Sew., Sphenobaiera angustifolia (Heer) Florin.

This assemblage justifies assigning the Londoko area coal measures to the Upper Jurassic or Lower Cretaceous. These formations are apparently correlative with the Bira coal-bearing deposits (Ugol'naya Sopka Village). Lithologically, they are essentially sandstones and stilstones. V.A. Vakhrameyev (personal communication) believes that, from a preliminary study of the two faunal assemblages, the coal measures of both the Londoko and Bira areas may be assigned to the Lower Cretaceous or the uppermost Jurassic.

Table 1
Stratigraphic differentiation of Mesozoic deposits in the areas of Londoko and Bira Stations on the Amur Railroad

Group	System	Class	S. V. Konstantov [5]. Left bank of the Bol'shaya Bira River; Ugol'naya Sopka area	S. I. Shkorbatov [14]. Area of Bira and Londoko Stations, Amur Railroad
Mesozoic (Mz)	Jurassic (J) and Cretaceous (Cr)	Upper Cretaceous (Cr_2)		<u>Extrusive sequence</u> Quartz porphyries, dacites, tuffs, and tuffaceous rocks
		Upper Jurassic and Lower Cretaceous (J_3^2-Cr_1)		
	Jurassic (J)	Lower, Middle, Upper (J_1-J_2-J_3^1)	E. Shales and sandy shales, light colored; 16 m. D. Typical gray tuffs of quartz porphyries and breccias with vitreous luster; 30 m. C. Conglomerates, greenish-yellow with argillaceous cement; mixed-grain sandstones, chiefly arkosic, yellowish-green to gray with <u>Dicksonia</u> <u>burejensis</u> Zal. imprints. Productive beds of Ugol'naya Sopka are associated with complex C; 120 m.	<u>Conglomerate sequence</u> Gray conglomerates with sandy cement, consolidated to friable; less common sandstones and shales. The sandstones are gray, arkosic, locally micaceous, with some tuffaceous material on top. Shales locally sandy, stratified, with thin intercalations of coal (1.0 to 10 cm), and plant remains; 250 to 300 m. Intrusions of biotite granite Poorly preserved plant remains and a fauna of pelecypods and brachiopods. <u>Tuffaceous quartz-porphyry sequence</u> Tuffs, quartz porphyries, and a small amount of clastic sedimentary rocks; 0 to 300 m.
	Triassic (T)			<u>Sandstone sequence</u> Sandstones, greenish-gray, micaceous and arkosic, interbedded with carbonaceous sandstones, shales and carbonaceous shales with coal beds of commercial thickness; 100 to 120 m. Tentatively assigned here are the Londoko and Birsk coal measures with four coal beds: the Sholokhovskiy, Bezymyannyy, Nikitinskiy, and Chupinskiy, each of varied thickness.
Paleozoic (Pz)			B. Tuffaceous rocks of porphyritic composition, with pebbles of underlying rocks; 150 m. A. Brown sandstones resting on crystalline schists (mica, chlorite, etc.).	Granite-gneisses, granodiorites

Table 1, continued

S. A. Muzylev [10]. Area of the middle channel of the Bol'shaya Bira River.	A. I. Arkhangel'skiy [2]. Area of Birsk coal field.
7. Dark shales; 110 m. 6. Dark conglomerates of fine pebbles, gray sandstones; 600 m. 5. Sandstones, light gray, arkosic, greenish shales; 500 m.	Birsk formation Pyroclastic sedimentary and extrusive rocks, underlain by acid tuffs and flows of varied composition, from acid (quartz porphyries) to basic (dolerite). In the middle part: tuffs, tuff lavas, tuffaceous siltstones and sandstones with four coal beds of workable thickness. At top: gravels; conglomerates with a tuffaceous cement and pebbles of underlying rocks (quartz porphyries and tuffs); 510 m.
	Langarinsk formation Sedimentary and extrusive rocks. At base: conglomerates with layers of sandstones and shales. In upper part: arkosic sandstones with lenses of conglomerates, and siltstone layers; five coal beds, each of varied thickness. Capped by a syenite-porphyry flow. Shales contain unidentifiable small thin-valved pelecypod and gastropod shells.
Langarinsk formation 4. Sandstones and shales, with thin conglomerates and layers of crumpled coal. A single coal bed of varied thickness; 250 m. 3. Sandstones, coarse grained, arkosic; 350 m. 2. Coarse conglomerates of granite pebbles; 20 m.	
1. Gray granites.	Biotite granites with numerous pegmatite veins; locally gneissoid.

However, this conclusion of V.A. Vakhrameyev calls for confirmation by a more comprehensive study of the plant assemblages, since the latter contain forms typical for both the upper part of the Jurassic and the Lower Cretaceous.

The S.I. Shkorbatov [14] stratigraphic column for the upper Mesozoic [14] shows a Jurassic "tuffaceous quartz-porphyritic sequence," as much as 300 m thick, resting above the "sandstone sequence." That sequence appears to be stratigraphically lower than our Upper Jurassic to Lower Cretaceous Birsk formation. The tuffaceous quartz-porphyritic formation of S.I. Shkorbatov's stratigraphic column is overlain by conglomerates, sandstones, tuffaceous rocks, and carbonaceous shales with layers of coal. He named that sequence, "the conglomerate sequence."

The age of the coal measures, as well as of the coarse-grained sandstones and conglomerates exposed in the right bank of the Bol'shaya Bira opposite Ugol'naya Sopka, and especially along the lower course of the Langara-1 River, can be determined only tentatively because of the lack of their floral and faunal characteristics. In this connection, S.I. Shkorbatov [14] states that cores from a borehole drilled in the Ugol'naya Sopka area contained belemnites, identified by G.Ya. Krymgol'ts as belonging to type Cylindroteuthis stimula and pointing to their Toarcian age. These deposits carry several coal beds of varied thickness. We have named them, the Langarinskaya formation, tentatively of a middle Lower Jurassic age. It is represented by conglomerates, polymictic and arkosic sandstones, siltstones and shales. Its total thickness reaches 720 m.

The name, "Langarinskaya formation," was first intruduced by S.A. Muzylev [10] to designate a coal-bearing layer on the left bank of the Bol'shaya Bira River, opposite Ugol'naya Sopka, which he assigned to the Triassic (Table 1). In our own nomenclature, Langarinskaya formation $J_{1-2}^{1?}$ comprises the entire sequence on the right bank of Bol'shaya Bira, including the conglomerates and finely clastic rocks with coal beds. Thus the presence of two coal-bearing sequences has been established for the Bira Station area: the upper, which is a member of the J_3-Cr_1^b Birsk formation; and the lower Langarinskaya formation $J_{1-2}^{1?}$.

The correlation of the tentatively middle Lower Jurassic Langarinskaya sedimentary formation and the Upper Jurassic to Lower Cretaceous Birsk formation, on one hand, with similar deposits from other localities, such as the Krasnyy Yar area on the left bank of the Koton River on the other hand, remains a moot question, because of the scarcity of data. According to S.I. Shkorbatov, the "conglomeratic sequence" is overlain by Cretaceous extrusive silicic rocks and their tuffs (rhyolites, dacites). These formations have been inadequately studied.

In 1935, S.A. Muzylev published a stratigraphic section for Triassic and Jurassic deposits from the area of the middle course of the Bol'shaya Bira. He differentiated Mesozoic sediments chiefly by lithology, as has been done above. It appears that the conglomerates and coarse-grained sandstones at the base of that section, as well as the coal-bearing rocks and the overlying Arkosic sandstones and greenish shales, should be assigned to the $J_{1-2}^{1?}$ Langarinskaya formation; and the gray fine-pebble conglomerates and sandstones, to the Birsk formation J_3-$Cr_1{}^b$ of our own stratigraphic outline (Table 1).

North and northeast of the Birsk coal field, Mesozoic deposits, particularly the coal-bearing, have been identified in troughs along the eastern edge of the Khingan-Bureya anticlinorium. They continue farther north and northeast, into the lower Amur synclinal zone. These coal-bearing deposits have been very inadequately studied [8]. Farther on, south and southeast of the Birsk coal field, there lies the immense and complex Amur-Sangari trough consisting of several synclinal structures which embrace Paleozoic and Mesozoic sediments [4, 9].

Coal measures have long been known from the area around Lobey, North Manchuria, within the Amur-Sungari depression, where they contain workable beds. Their age can be tentatively determined as Upper Jurassic and Lower Cretaceous.

South of these coal exposures, there lies the Khegan coal region, one of the largest in northern Manchuria. According to Khe Si-Lin' [13], this region is chiefly made up of the Khegan coal measures consisting of three beds -- the upper, middle, and lower -- with a total thickness of as much as 1400 m. The Khegan coal measures are represented chiefly by sandstones, shales, conglomerates, tuffs, and coals, carrying fossil ferns of the genera Cladophlebis, Coniopteris, Ruffordia, Onychiopsis; ginkgo genera Ginkgo, Baiera, Phoenicopsis, Czekanovskia; cycadaceae genera Taeniopteris, Nilssonia; some coniferous genera, Podozamites, Pityophyllum, Elatocladus; and horsetail genera Equisetites and Neocalamites.

Khe Si-Lin' [13] assigns the lower coal-bearing bed to the Middle Jurassic; and the middle and upper, to the Upper Jurassic.

However, V.A. Vakhrameyev,[2] in a footnote to his report on the Khe Si-Lin' work [13], states that Ruffordia geoppertii Dunk. and Onychiopsis elongata (Geyl) Jok., from the middle bed, are distributed mostly in the Lower Cretaceous. On the other hand, the deposits of the same bed contain Coniopteris hymenophylloides Brogn., Neocalamites sp., and other forms, usually associated with the Jurassic. On the basis of these facts, the middle and upper beds of the Khegan coal measures may be assigned to the Upper Jurassic and Lower Cretaceous.

The older, Middle Jurassic, age of the lower bed calls for more study.

It should be noted that Upper Jurassic and Lower Cretaceous coal measures east of the Malyy Khingan Range, which are contemporaneous with the western Amur region coal measures, carry plant forms typical of younger coal-bearing deposits.

The presence of related faunal assemblages in the upper Mesozoic of various areas of the western Amur region was noted early, by many students. V.A. Vakhrameyev, who studied the Zeya flora of our 1950-1951 collections, regards it as identical with that from the Bureya coal basin. This, according to him, justifies their assigning to the same Upper Jurassic-Neocomian age.

V.D. Prinada [11] believes that the entire Zeya floral assemblage fits into those of the adjacent Bureya and upper Amur regions. He believes their age to Upper Jurassic.

According to A.N. Krishtofovich [6], the general aspect of the Bureya flora differs but little from that of upper Amur flora. He states that the Bureya flora is dominated by ferns, with a considerable part played by ginkgoes and cycadophytae, with the conifers insignificant. A.N. Krishtofovich has assigned the Bureya Basin coal measures to a special Amur stage, stratigraphically higher than the Irkutsk stage but lower than the Nikan. According to him, the Amur stage flora is very similar to the Tetori flora of Japan.

The difference in the stratigraphic position as established by various students for the western Amur region coal measures is explained, to a considerable extent, by the inadequate knowledge of floral assemblages from these sequences. After a comprehensive study of their biostratigraphic features, these rocks probably will be differentiated into a number of Cretaceous and Jurassic formations.

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[2]See report on the work of Khe Si-Lin' [13]. "Geologiya," no. 2, Akademiya Nauk U.S.S.R., 1954.

Thus, the present status of knowledge for floral assemblages of the above-named regions establishes a contemporaneous age for the upper coal measures, assigned to the Bol'shaya Bira Basin Birsk formation (J_3-Cr_1)^b, and those of the Zeya and Bureya Basins. The lower coal measures, assigned to the $J_{1-2}^{1?}$ Langarinskaya formation, is apparently correlative with those of the J_{1-2} Butefskaya formation of the upper Amur coal region. The age correlatives of the lower $J_{1-2}^{1?}$ Langarinskaya formation and of the Butefskaya $J_{1-2?}$ coal measures are missing and the corresponding interval is represented by marine facies. In the Zeya Basin, within the southern part of the Zeya coal area, the conditionally middle Lower Jurassic deposits are represented by platform facies, with inconspicuous coal shows.

In the Khegan coal region, the upper and middle coal beds of the J_3 Khegan series appear to be contemporaneous, according to Khe Si-Lin' [13], with the upper coal measures, assigned to the J_3-Cr_1^b Birsk formation; whereas the lower coal bed of the same J_2 [sic] series is correlative with the lower coal measures of the $J_{1-2}^{1?}$ Langarinskaya formation, in the Bol'shaya Bira Basin.

The above-named composition of fossil-plant assemblages from coal measures in the basins and fields east of the Malyy Khingan Range and adjacent areas of the western Amur region, differs in floral assemblages from the Trans-Baikal coal measures. The latter consist, according to V.D. Prinada [12], chiefly of ginkgoes: Phoenicopsis and Czekanovskia; conifers: Podozamites and Pitophyllum; and ferns: Sphenopteris, Cladophlebis; all existing from the Middle Jurassic to Early Cretaceous. This plant assemblage consists chiefly of ginkgoes and conifers, with ferns in a subordinate position; whereas ferns, ginkgoes, and cycadophytae are the main component of floral assemblages for Upper Jurassic and Lower Cretaceous coal measures from the western Amur region and the adjacent part of Manchuria.

The predominance of ferns, with a considerable development of ginkgoes and cycadophytae and a subordinate position of conifers, in coal measures of those two provinces lend substance to the assumption of an upper Mesozoic upper Amur floral province (the upper and lower courses of the Amur) located at the southern edge of the Siberian botanic-Geographic province [3].

II. TECTONIC AREAS AND THE PHASES OF COAL ACCUMULATION

A tectonic differentiation of the Mesozoic

coal accumulation in the western Amur region and adjacent parts of the Far East is of a great practical value because it provides a basis of tectonic evidence for the search of coal. Three principal tectonic areas have been recognized in the region under study, as of prime importance in the process of coal accumulation. They are: the Zeya-Bureya shield; the western Amur area of development of the foredeep type Mesozoic folding; and the area of Mesozoic (Verkhoyansk or Pacific) geosynclinal folding, widely developed east and north of the Khingan-Bureya anticlinorium.

Corresponding to this tectonic differentiation, three types of coal accumulation have been recognized: 1) the platform type, genetically related to platform structures of Cenozoic folding (middle Amur brown coal basin, etc.); 2) geosynclinal type prevailing within synclinal zones of Mesozoic (Verkhoyansk) folding (Suchan and other coal basins); and 3) the area of development of the foredeep type structures of Mesozoic folding (Zeya coal area, Bureya coal basin, and their correlatives).

Within these tectonic areas, the upper Mesozoic coal accumulation proceeded in three phases: 1) Middle Jurassic and possibly Lower Jurassic; 2) Upper Jurassic to Lower Cretaceous; and 3) Upper Cretaceous and Tertiary. Phases one and two are associated with the late and middle structural stages of Mesozoic folding; phase three, with Cenozoic folding.[3]

East of the Malyy Khingan Range and in adjacent areas of the western Amur region, Upper Jurassic and Lower Cretaceous coal measures of phase two are best developed. They are main components of the Zeya coal area, the Bureya coal basin, the Birsk coal field, and their correlatives. The coal measures of phase one have been very inadequately studied and are known only from the upper Amur region and the Birsk coal field. The coal measures of phase three are very widely developed, both in the western Amur region and the adjacent Far East provinces.

The formation of coal basins of types two and three is related to a prolonged downwarping of the earth's crust in the presence of oscillatory movements. The latter were responsible for the accumulation of thick coal measures with a large number of coal beds. Such conditions of coal accumulation are characteristic of geosynclinal provinces and their foredeeps. The prolonged sinking or downwarping of the earth's crust did not take place during the formation of coal basins of type one on platforms; accordingly, only comparatively thin coal measures were formed there with only a few beds of brown coal.

All of the above-named coal basins are made up of sedimentary formations whose composition is closely related to their belonging to one or another tectonic area, on one hand; and to the paleogeographic and climatic conditions of the coal-making time, on the other. Type one of coal basins, genetically related to platform structures, is characterized by slightly disturbed, comparatively thin Upper Cretaceous and Tertiary coal measures. They are made up chiefly of nonmetamorphosed sedimentary rocks: sands and clays with a few beds of brown coal, apparently deposited in river valleys and in depressions of a marshy lacustrine network. Among the general features characteristic of coal measures of the Zeya coal area and the Bureya coal basin, which are the two best known representatives of type three basins, are the following: 1) their considerable thickness, as much as several thousand meters; 2) a large number of coal beds; 3) a comparatively high degree of metamorphism (consolidation) of coals and the enclosing rocks; and 4) the presence of sediments which form fan cones and fill river valleys and the marshy-lacustrine depressions in intermontane plains.

Upper Jurassic and Lower Cretaceous coal measures, the main components of the type two basins, chiefly associated with the synclinal zones of Mesozoic (Verkhoyansk) folding, are inadequately known, with an exception of the Suchan and Suyfun Basins, which are outside the area under study. It should be noted that structural features of the geosynclinal-type basin coal measures are similar to those for coal measures genetically related to the foredeep type structural forms. All of these coal basins are marked by the presence of two groups of coal: brown and hard. The formation of brown coals is genetically related to platform structures, as has been touched upon above. The formation of hard coals took place within the foredeep-type structural forms and in synclinal zones of Mesozoic folding. The Zeya and Bureya hard coals, whose formation has been related to the foredeep-type structures, are generally marked by their high ash content and by being exceedingly resistant to enrichment. On the other hand, the Birsk, Khagan, and Suchan hard coals, having originated in synclinal folds of Mesozoic folding, east of the Khingan-Bureya anticlinorium, have a lower ash content and a fair enrichment capacity. The ash content in brown coals formed under platform conditions is relatively low.

A more detailed description of the coal grades is given in our 1957 work.

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[3]The differentiation into structural stages has been made on the basis of "the Tectonic Map of the U.S.S.R.," edited by N.S. Shatskiy, 1952.

III. COAL PROSPECTS

A.N. Krishtofovich [6] was first to voice an assumption of the presence of Jurassic coal measures beneath the Tertiary and Quaternary mantle in the basins of the Bol'shaya Bira and Bidzhan Rivers. He compared the practical value of this area to that of the Khegan coal region, in the lower Sungari Basin.

Recent geologic and geophysical study has not revealed a broad development of Jurassic deposits in that area. However, as a result of the 1952 work of T.G. Gretsova along the lower course of the Bidzhan, sedimentary formations have been discovered there which are similar to the Birsk coal measures, judging from geophysical data.

A probable presence of Jurassic and Lower Cretaceous coal deposits in the lower Bidzhan Basin and adjacent areas of the Amur-Sungari trough is confirmed by the presence of workable coal beds in the Birsk and Lobey coal fields and in the north Manchurian Khegan coal region. Two prospective areas can be separated, at the present time, east of the Khingan-Bureya anticlinorium. The first is located in the basins of the Bol'shaya Bira, Bidzhan, Urmi, and Sungari Rivers; the second includes the central and eastern parts of the Mesozoic (Verkhoyansk) geosynclinal province. The presence of the Suchan and Suyfun coal basins within the latter suggests the possibility of finding new coal deposits in the Soviet Far East and adjacent parts of China, as noted by P.N. Kropotkin [8].

Of a practical value in the western Amur region are Upper Jurassic and Lower Cretaceous coal deposits formed within the foredeep-type structures. Such downwarps fringe the northern part of the Zeya-Bureya shield (Bureya coal basin, Zeya coal area, upper Amur coal region, etc.). No similar coal deposits have been found in northern Manchuria.

The prospects for new Upper Cretaceous and Tertiary coal deposits, east of the Khingan-Bureya anticlinorium and within the Zeya-Bureya shield are increased by the presence of the Kivdo-Raychikhinskiy and Ushumun brown coal deposits.

CONCLUSIONS

1. Coal measures, the main component of the Birsk coal field and Khegan coal region, belong to the Upper Jurassic and Lower Cretaceous and are contemporaneous with the Zeya and Bureya Basins' coal measures.

A tentatively middle Lower Jurassic coal-bearing interval has been found in the Bureya field, below the upper sequence. Its practical value has not been demonstrated.

2. East of the Malyy Khingan Range and in adjacent areas of the western Amur region, three upper Mesozoic phases of coal accumulation have been recognized: 1) Middle and possible Lower Jurassic; 2) Upper Jurassic and Lower Cretaceous; 3) Upper Cretaceous and Tertiary.

Phases one and two are associated with the late and middle stages of Mesozoic folding; phase three is associated with Cenozoic folding.

3. By their structural features and history of tectonic development, coal basins east of the Malyy Khingan Range and adjacent areas of the western Amur region are divided into three types: 1) platform; 2) geosynclinal; 3) genetically related to structural forms akin to foredeeps.

4. The Amur-Sungari trough, specifically along the lower courses of Bidzhan and Sungari, may be recommended as the prime objective of geophysical, geologic, and drilling work for the purpose of discovering new deposits of coke coal of the geosynclinal type.

The search for new coal deposits genetically related to the foredeep-type structural forms in the western Amur region, because of the low grade of their coal, will be justified only in areas of favorable economic conditions (water transport, a short haul to the consumer).

The search for new Upper Cretaceous and Tertiary brown coal basins, within the western Amur region and adjacent provinces of Manchuria is justified in the area of distribution of platform structures.

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STRUCTURE OF THE SOUTHWESTERN EDGE OF DONBAS (AN ANALYSIS OF THE CHANGE IN THICKNESS OF THE COAL MEASURES)[1]

by

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The problem of the Donbas structure has long held the attention of its students [1-6, 11, 13-17]. Their publications dealt with the uniformity in the thickness change of the Donbas coal measures [3-5, 14, 16]. Up to now, however, geologists are far from any agreement on this subject. A review of different theories is given in recent publications [2, 5, 10, 15, 17].

Most controversial is the problem of the relationship of the Ukrainian crystalline massif to the Donbas Paleozoic. In this respect, a study of the pattern in the change in thickness of deposits in the southwestern part of the basin is particularly urgent.

In the last few years, geologic prospecting has been very active in this area. The numerous data thus obtained, substantially refine the popular concept of its geology. From the new data of the geologic survey and those obtained from more than a thousand boreholes of the "Artemuglegeologiya," the author was able to make a detailed study of the change in formation thicknesses within the Donbas southwestern belt, extending for 160 km from the Samara River in the west to the Kal'mius and Krynka Rivers, in the east.

An analysis of the data on the thickness of coal deposits in southwestern Donbas reveals the following patterns, common to all formations:

1. The isopachs trend northwesterly, corresponding to the outline of the crystalline massif.

In a first approximation, isopachs for all formations coincide in direction. Going northwest, toward the central zone of the Donets downwarp, the isopach intervals gradually grow larger, whereas the upper formation isopachs veer fanlike to the north-northwest.

2. The thickness of all formations increases to the northeast.

Our isopach maps, constructed from new data for the upper, middle, and lower Carboniferous are on the whole similar, thus suggesting that the change in thickness for deposits in southwestern Donbas proceeded along the same general plan, during all of the Carboniferous.

For this reason, we use only two isopach maps to illustrate this brief exposition (for the Upper and Lower Cretaceous). Another reason is that the new data fit well in the overall picture of the thickness change as established for the Donets downwarp by A.Z. Shirokov [14] on the productive middle Carboniferous interval, whereas the V.Z. Yershov isopach maps [4] for formations C_2^3-C_2^7 required correction only in detail. On the other hand, there are no similar published data on the Lower and Upper Cretaceous.

The most complete data on the increase in thickness for formations in southwestern Donbas come from the south Donbas and Stalino-Makeyevka geologic industrial districts. They are compiled in Table 1.

In Table 1, columns 2 and 3 show the extreme formation thicknesses taken into account. The distance between the determination points is shown in column 4, with the distance measured normal to the isopachs, i.e., in the direction of the maximum increase rate.

Inasmuch as the average thickness increase per 1 km, across the deposition strike, as shown in column 9, refers to intervals of different absolute thickness, it does not adequately characterize the dynamics of the process. In order to obtain correlative figures, we have computed in addition, the average increase rate for 100 m of each formation (i.e., the percent increase over 1 km across the isopach trend; column 8).

An analysis of the average thickness increase, over 1 km across the isopach trend,

[1]K voprosu o strukture yugo-zapadnoy okrainy donetskogo basseyna.

Table 1
The thickness change for coal-measures along line south Donbas -- Stalino-Makeyevka districts

Formation	Thickness (m)		Distance between points, across the isopach trend (km)	Absolute increase in thickness (m)	Average increase in thickness, across the isopach trend	Average thickness of formation in interval under study (m)	Average increase in thickness for 1 km, across the isopach trend (% km)
	Minimum	Maximum					
C_1^2	405	545	19	140	7,4	475	1,6
C_1^3:							
Lower member	372	657	27	285	10,6	515	2,0
Upper member	260	480		220	7,9	370	2,2
C_1^4	225	535	25	310	12,4	380	3,3
C_1^5	272	495	25	223	8,9	383	2,4
C^2_1	125	267	32	142	4,4	196	2,2
C_2^2	260	445	28	185	6,3	352	1,9
C_2^3	285	447	0	162	5,4	366	1,5
C_2^4	195	319	37	124	3,3	257	1,3
C_2^5	238	520	35	282	8,1	329	2,4
C_2^6	160	360	38	200	5,2	260	2,0
C_2^7	300	630	32	330	10,3	465	2,2
C_3^1	420	830	36	410	11,4	625	1,8
C_3^2	545	1090	38	540	14,2	815	1,7

NOTES:
a. The direction of the thickness change for formations C_1^1 and C_3^3, from fragmental data, is similar to that for other intervals; however, the data are inadequate for computations.
b. The differentiation for C_1^2 and C_1^3 is from the 1954 "Artemuglegeologiya" map.

Note: Comma represents decimal point.

revealed the following patterns:

1. The rate of the thickness increase varies in a comparatively narrow range, being 2.0±0.4% per km. An exception is formation C_1^4, marked by a higher rate of change (3.3%/km), and formation C_2^4, with a somewhat lower rate (1.3%/km).

This isopach pattern for the lower, middle, and upper Carboniferous formations, as established from actual observations, along with the same direction of the thickness increase for all formations and with the narrow range of the rate change, leads to the conclusion that the proportional thickness change rule, originally established by V.Z. Yershov [4] for the middle Carboniferous, is applicable to all of the coal measures of southwestern Donbas.

To be sure, the fluctuations in the thickness change rate imply certain deviations from the proportionality rule. However, the magnitude of these deviations does not exceed 20% for all formations, except C_1^4 and C_2^4.

This rate of change increases gradually from C_1^2 (1.6%/km) to C_1^4 (3.3%/km), then gradually decreases to a minimum of 1.3%/km, in C_2^4. It increases sharply again, to 2.4%, at the outset of Moscovian time (C_2^5); later on, it tends to decrease gradually.

There seems to be a definite relationship between the rate of the thickness change which reflects the differential vertical movement of the area, and the facies composition of the section. The higher the rate of change, the more intensive the facies changes.

The maximum rate, in C_1^4, corresponds to the extremely motley facies aspect of that formation.

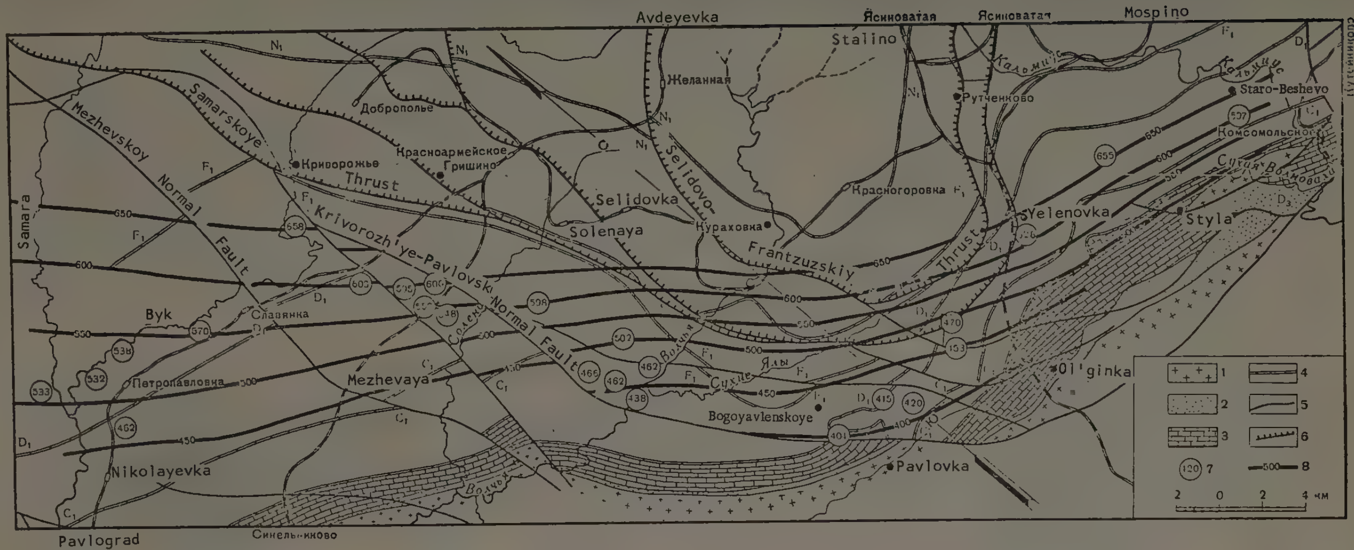

FIGURE 1. Isopach map for the lower (coal-bearing) member of the Samarskoye formation C_1^3.

1 -- Outcrops of Precambrian crystalline rocks; 2 -- Upper Devonian outcrops; 3 -- outcrops of $C_1^t + C_1^v$a-f limestones; 4 -- limestone outcrops in terrigenous Carboniferous; 5 -- normal faults; 6 -- thrusts; 7 -- thickness control data; 8 -- isopachs.

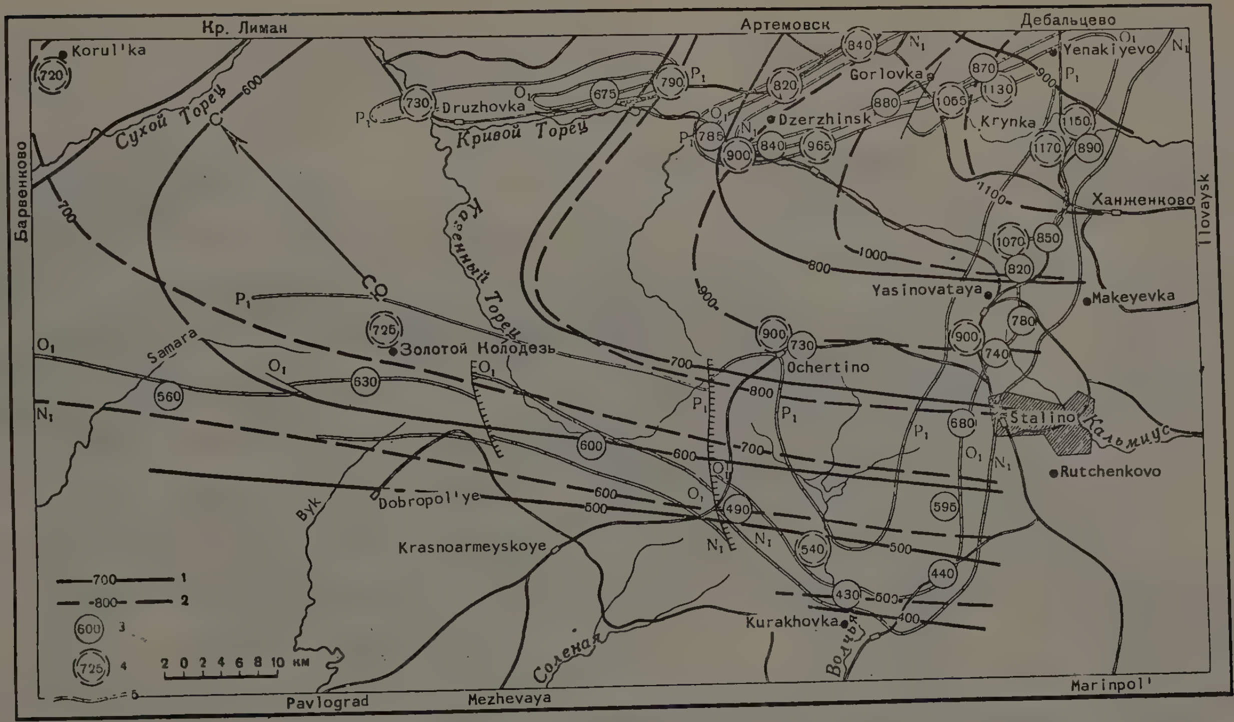

FIGURE 2. Isopach map for formations C_3^1 and C_3^2 in southwestern Donbas.

1 -- Isopachs for C_3^1 formation; 2 -- isopachs for C_3^2 formation; 3 -- control data for C_3^1; 4 -- control data for C_3^2; 5 -- outcrops of limestone marker beds.

As against that, formation C_2^4 with a minimum rate of the thickness change, is marked by the consistency of its facies over very large areas.

The rate of the thickness change, across the isopach trend and toward the edge of the crystalline massif, is not strictly constant throughout the area. There is a definite tendency for its increase to the southeast. Thus for C_1^3 along the Samara, it is 1.6 to 1.7%/km, whereas it is 2.0 to 2.2%/km in the south Donbas district. The drop in the thickness change rate to the northwest, is reflected in the above-mentioned fan-shaped divergence of the isopachs, in that direction.

Table 1 gives the averages for the thickness change rate over considerable distances (25 to 30 km), along the dip and toward the crystalline massif. In that range, the formation thicknesses change very smoothly, as a rule, so that the actual rate of change is close to the average, even over shorter stretches (5 to 10 km). Local deviations, due to various causes, comewhat complicate the general picture without changing it.

The most interesting and significant anomalies result from abrupt changes in thickness, associated with the fault system, of which the largest is the Krivorozh'ye-Pavlovskiy regional normal fault which is traceable 130 km to the northwest, with a throw of 900 to 1200 m.

The sediments are much thicker on the down-thrown northeastern blocks of these faults, than they are in the up-thrown southwestern blocks. The metamorphism of their coals changes correspondingly and abruptly.

The totality of data suggests the co-sedimentary development of these faults. We regard them as ancient regional features whose formation, in connection with the sinking of the Donets trough, persisted into the Devonian, lower Carboniferous, and the Bashkir stage of the middle Carboniferous.

The progressive southeasterly thinning of Carboniferous deposits is accomplished chiefly through the thinning of all component elements of the section and partly through a wedging-out of some beds and the appearance of intraformational hiatuses. The latter are typical of the peripheral area and have been definitely established only for the lower Carboniferous.

A clean-cut fault, west of Petropavlovka and in the south Donbas district, is related to the maximum Namurian differential vertical movement which is reflected in the higher rate of change in the overall thickness of formations C_1^4 and C_1^5. Its throw increases southwest, toward the crystalline massif, attaining 150 m at Bogoyavlenka. No definite break has been observed at Kal'mius.

An extrapolation of the data suggests that a short distance (about 10 km) southwest of the present boundary of the coal measures, in southwestern Donbas, their thickness decreases to where it is quite atypical of the old Donbas (C_1 about 1200 m thick; C_2 about 800 m), but close to their thickness over the near-platform edges of the Dnieper-Donets trough.

The change in the thickness of the deposits is accompanied by the change in the metamorphism of coals and rocks of the area. Going from southwest to northeast, in the direction of the thickening, the coals are gradually upgraded, over a stretch of 25 to 30 km, from long flamed or gaseous to lean.

The above data militate against the possibility of accumulations of very thick coal measures of the Donets type, in the area of the Ukrainian crystalline massif, and particularly in its Azov block. The condemn, as unfounded, the view which holds these two structures to be the eroded core of a Hercynian anticline -- the view advanced in different variants by some students [5, 11, 12].

On the other hand, a detailed study of the lithology, the facies, and the sedimentation conditions, also contradicts the hypothesis of a Carboniferous mountainous land near the southern reaches of the basin. The insignificant part of coarse clastics in general, and of alluvial deposits in particular, in the lower Carboniferous section, along with the well-rounded psephitic grains (quartz, metamorphic rocks) and the predominance of littoral-marine and continental facies with a low mobility of their environment -- all this suggests the long distance from a mountainous land which was the source of the sediments.

If this is true, the Azov block of the Ukrainian crystalline massif in the Carboniferous, was neither an area of thick sedimentation nor a mountainous land (as conceived by some geologists who believe the Donets Basin to have been a foredeep). In our opinion, the crystalline massif in the Carboniferous, was a site of periodic sedimentation and erosion. In times of general transgressions, the massif underwent an accumulation of sediments, being temporarily submerged. In the periods of regression, it underwent denudation. The clastic material, dumped into the Donets downwarp from a source area far to the southwest, lingered but for a short time on a nearly flat plain, and on a but slightly mobile crystalline massif.

The Krivorozh'ye-Pavlovskiy fault and a zone of associated smaller faults divide the southwestern Donbas edge into two parts, marked

by different tectonic features.

Southwest of this fault zone, the tectonics is determined by the proximity of a rigid crystalline basement. The rocks rest with a monoclinal dip, complicated only by block movements along the fault planes. The local tectonics is radically different from that in the older districts of the Donets basin.

Northeast of the zone of regional faults, the rock position has been complicated by a secondary folding, with local brachistructures; the faults are chiefly reverse. The tectonic forms begin to acquire a Donets aspect.

The change from the first to second tectonic type is not abrupt. Both types are interwoven in a belt, several kilometers wide, along the Krovorozh'ye-Pavlovsk fault.

Thus, the northeasterly thickening of Carboniferous sediments is accompanied by a change in tectonic forms, which suggests that quantitative changes here are combined with a radical change in the geotectonic conditions. Accordingly, on the basis of this evidence, we regard the Ukrainian crystalline massif -- including its Azov block -- as an upper Paleozoic platform area. This view is shared by many other students [1, 2, 6, 7, 13-17].

The sedimentary complex of southwestern Donbas is located in the area of the northern slope of the platform and on the south part of the Donets downwarp, with an environment transitional from the platform to geosynclinal.

A similarity with the southern edge of the Dnieper-Donets trough is readily seen in this structural picture of the southwestern rim of the Donbas. In both places, there are no radical differences in the pattern of the thickness change for Carboniferous deposits and in the general tectonic plan. This suggests a genetic relationship between the two regions, expressed in a common sedimentary basin and in the community of their main structural elements. The Krovorozh'ye-Pavlovsk fault zone is, in our opinion, correlative with (or continuation of) the peripheral faults bounding in the south the central graben of the Dnieper-Donets trough. In any event, the belt southwest of these regional faults represents a platform slope of the Ukrainian crystalline massif, whereas the central zone of the Dnieper-Donets trough, gradually widening to the east, is connected with the central structures of the Donets Basin.

These views contradict those held by some students [8, 9] who assume the presence of a meridional fault zone separating the radically different -- in their opinion -- areas of the Dnieper-Donets trough and Donets Basin proper.

The temptation is great, to use the general structural similarity in the south part of the Dnieper-Donets trough and southwestern rim of the Donbas, in an attack on some unsolved problems in these areas.

Thus, it is conceivable that segments of thick Devonian deposits are present in the down-thrown side of the Krivorozh'ye-Pavlovsk fault, as against the up-thrown block where a thin Devonian section has been established. The presence of Devonian salt deposits cannot be ruled out; it is indirectly suggested by the highly mineralized chlorine-sodium waters in some of the boreholes in the vicinity of the Krivorozh'ye-Pavlovsk fault.

The morphology of some of the minor structures (such as the Pavlovsk dome) does not militate against their being related to salt tectonics.

The totality of data makes it urgent to explore the southwestern rim of the Donets Basin for oil and gas prospects similar to the known fields of the Dnieper-Donets trough (Radchenkovo, Zachepilovka, Mikhaylovka, etc.).

The presence of favorable structures, with a comparatively low degree of metamorphism (consolidation), as well as some indirect evidence (mineralized waters of the oil field type and gas shows in some core holes), gives priority to the western part of the south Donets Basin as a fruitful area for geophysical and exploration work for oil and gas.

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BRIEF COMMUNICATIONS[1]

DEVONIAN VOLCANIC NECKS IN THE NORTHWESTERN MINUSINSK DEPRESSION[2]

by

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The thick extrusive flows in the Lower and Middle Devonian on the rim of the Minusinsk depression postulate the presence of a means for the magma to get from the depths to the surface. In the literature on Devonian extrusives from the rim of the Minusinsk depression, this means of escape is described as being hypothetic fracture zones and linear elements. None of these hypothetic phenomena has been observed. The numerous dikes cutting Lower Devonian sedimentary and volcanic rocks, and regarded as "the roots of Devonian extrusives," cannot be such, because their composition is different from the flows, and they, in most instances, cut the entire thickness of the flows. The inner structure of these dikes, too, militates against their being channels for the flows, because they do not carry, as a rule, either glass nor clastic material.

Among the many students of Devonian extrusives of this region, A. I. Aleksandrov alone mentions three ancient volcanic necks — in his as yet unpublished work -- in the Sve and Soryb Mountains and in the Sakhtyb Valley, all located on the Kuznetskiy Alatau eastern slope, in the Uybat Basin. In 1957, we succeeded in finding four more necks in that area.

A brief morphologic description of the known necks is given below.

The Sve Mountain neck is located in the Ninya-Nemir-Sakhtyb interfluve area, on the south slope of the Ustanak massif. Morphologically, it is a monadnock with an asymmetric top and nearly sheer sides, 35 to 60 m high. The eastern part of the top is a more or less horizontal platform; the southern, a peak standing 20 to 25 m above it. The neck is elliptic in cross section, elongated from north to south; its northern part is narrowed, with an uneven, angular, and serrated contact with the enclosing rocks; the neck is 350 x 300 m.

The Sakhtyb Valley volcanic neck, unlike all others, is located not on a mountain top, but on the right side of the Sakhtyb River valley at its confluence with the Konkhosa. It is seen in a rock outcrop, 130 to 150 m high, as a column with a diameter of about 800 m, slightly tilted to the east. Its contacts are angular and serrated.

The Soryb Mountain volcanic neck is exposed in its smooth south face in a sheer wall 30 to 40 m high, on the south slope of the Soryb. The neck is made of brecciated marbles cemented by a tuffaceous lava material. It appears from isolated outcrops, that this volcanic neck is elliptic in plan and elongated from east to west. It measures 800 m from east to west, and 500 m from north to south.

A study of thin sections of rocks from all these necks has demonstrated the perfect analogy in their composition, texture, and structure.

All three necks display three more or less definite zones of rocks different in their composition and structure. The contacts of these zones are so complicated as to defy all efforts towards their exact determination. Generally speaking, the three zones are as follows: the peripheral, made up of brecciated lateral rocks cemented by a tuffaceous lava material; the middle, made up of assorted fragments of various sizes and of blocks of psephitic lithoclastic rocks cemented by the tuffaceous lava material; and, finally, the central, presenting a vent of bizarre form, filled with a

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[1] Melkiye soobshcheniya

[2] Vulkanicheskiye zherloviny devonskogo vozrasta severo-zapadnoy chasti minusinskoy kotloviny.

lava material of noncrystallized glass carrying a few plagioclase phenocrysts with some fragments of lithoclastic tuffs fused in the phenocrysts.

The outline, position, and dimensions of each zone change along the neck. However, where all three zones are present, the first one occupies the peripheral part of the neck; the second, the middle part; and the third, the central.

The peripheral zone rocks are brown to greenish brown; their texture is crystalline. The clastic material is represented by isolated and fused extrusive fragments of assorted sizes, less commonly by fragments of sandstones and marblelike limestones. Present among the extrusive fragments, are amygdaloid albitophyres with a hyalopilitic groundmass texture; andesites with a microlithic and hyalopilitic groundmass; and quartz felsite-porphyries with felsitic and spherulitic textures. The sandstone fragments are fused and consist of rounded grains of quartz, feldspars, and siliceous rocks, held together with a carbonate cement. The limestone fragments are corroded. The material which cements these fragments is of varied composition and texture. In most places it is andesite or andesite-dacite with a hyalopilitic texture. The composition of porphyry inclusions is inconsistent, fluctuating in a wide range from oligoclase No. 12 to andesine No. 40.

The groundmass consists of poorly defined microliths, usually of completely saussuritized plagioclase, immersed in noncrystallized, commonly opaque dark-brown glass. Unevenly dispersed in this groundmass are aggregates of chlorite and ore substance, probably replacing the pyroxene as is suggested by their outlines.

The middle-zone rocks differ from those of the peripheral by the absence of fragments of the amygdaloid rocks and quartz felsite porphyries. Their main components are andesite-dacites and andesites described above as the cementing material. These rocks are characterized by the peculiar "multiple" breccias. A fragment fused in andesite represents, in turn, a portion of the cementing mass with andesite or andesite-dacite fragments fused in it. A study of thin sections from that portion of the volcanic neck has revealed four "generations" of breccias in a single fragment.

The cementing mass, in the first instance, represents a normal andesite, less commonly andesite which may be regarded as andesite-basalt because of its higher than usual content of dark components. Other than that, the cement of the middle zone is as described above.

The central-zone rocks are marked by the scarcity of fused-in fragments and by a consistent composition. Among the component rocks, for different necks, are andesite-dacites, andesites, andesite-basalts, and trachyandesites. All these rocks are marked by a large amount of noncrystallized colorless to brownish nonpolarizing mesostasis in the groundmass, and by the latter's hyalopilitic, pilotaxitic, or trachytic texture.

The composition of the andesite-dacite and andesite varies in a comparatively narrow range, from No. 15 oligoclase to No. 30 andesine. The trachyandesites contain inclusions of K-feldspars and augite, whereas the andesite-basalts carry inclusions of No. 40-50 labradorite. The plagioclase inclusions are nearly fully saussuritized. The K-feldspars, intensively pelitized, are commonly rounded, with a peculiar radial structure and sector extinction, like that of the aggregates of zeolites or chalcedony, except that the fading sectors are more definite in K-feldspar, and distributed without apparent order. The number of sectors, fading simultaneously with a turn of the microscope table, is varied.

These volcanic necks are located within Devonian extrusive flows or near them. The composition of their rocks is quite similar to that of the flows. Thus genetic relationship is established from petrographic as well as from the geologic data.

The study of the extrusive flows made it possible to discern a rhythm in the composition of the volcanic material and to establish periods of abated volcanic activity.

Generally speaking, each new cycle opens with a flow of andesite-basalts, locally even of diabases, changing to andesites, and finally to andesite-dacites and even to quartz felsite-porphyries at the close of the cycle. Those intervals of a cycle which are marked by andesite and andesite-dacite flows carry layers of volcanic bombs.

Periods of relative quiescence are reflected in the accumulation of conglomerates with a tuffaceous cement and of tuffaceous sandstones.

The total thickness of each cycle is 300 to 400 m, with rocks of different composition grouped as follows in the decreasing order of their thickness: andesites, andesite-dacites, tuffaceous sandstones and conglomerates, and andesite-basalts. Altogether four cycles have been counted in the area under study.

Thus, the structure of the volcanic necks, and the composition of the rocks, suggest an explosive character of the eruptions responsible for the flows. The presence in the necks, of many "generations" of breccias, suggests their recurrent activity as instruments of volcanism. Finally, the composition of rocks

from different neck zones, along with the rhythmicity of accumulation of the extrusive material, makes it possible to arrive at a preliminary conclusion on the change in the magma composition during a single cycle of intensive volcanic activity.

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PLASTIC DEFORMATIONS IN LIMESTONES FROM ZONES OF SHATTERING ACCOMPANYING MAJOR FAULTS[3]

by

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Very large deforming stresses are known to originate in the zones of shattering which accompany major faults. The magnitude of such stresses, and their effect on rocks, are not always readily ascertainable. It is difficult to evaluate the character of the deformation if the initial form of the deformed body is unknown; it so happens that the instances when this original form is known are very rare.

Conglomerate pebbles are an excellent subject for observing the character of the rock deformations. Each pebble presents a rock sample for nature to experiment upon (as to its mechanical properties) by placing it in a natural press and by subjecting it to temperatures and pressures characteristic to a given tectonic zone, with the "experiment" proceeding without a distortion of the time scale. The original form of the "sample" (pebble) and the structure of its component rock can be studied in the conglomerate outside the shattered zone; whereas the changes in the "sample" during the "experiment" are studied in the shattered zone conglomerate. Thus, a study of pebbles from conglomerates in the shattered zone affords a chance to judge the character of deformations which take place in a rock, as an effect of tectonic forces acting in these zones.

To determine the character of deformations in limestone, in a shattered zone, we studied limestone pebbles from a Devonian conglomerate in the Akbastau fault zone, central Kazakhstan (13 km east-north-east of railroad station Kiik, north of the Kamela Mountain). In the vicinity of the Kamela Mountain, Devonian conglomerates are exposed in a faulted tectonic block. The conglomerates have only been slightly dislocated in the central part of the block. They dip at about 10 to 12° and are not at all schistose. Immediately adjacent to the fault, and within the shattered zone accompanying it, the deformation of conglomerates increases abruptly. The dip of the beds remains the same but the rock is strongly schistose. A comparison of the conglomerate structure in the center of the block and in the shattering zone readily reveals the substantial changes in the latter. Especially intensive is the change in limestone pebbles.

In the slightly dislocated central part of the block, conglomerates consist of pebbles of assorted sizes, closely pressed to each other, with a small amount of cement filling between them and consisting of a calcareous sandstone (Fig. 1). More than 90% of the pebbles are of limestone, with the remainder, sandstones, quartzites, siliceous rocks, and diorites. In some isolated layers, the amount of nonlimestone pebbles is considerably larger.

The limestone pebbles are, as a rule, well rounded, and are usually from 2 to 15 cm, with most of them 5 to 10 cm. There are a few large boulders. The pebbles are usually spheroidal to elliptic, with the axes ratio of 3:3.5:4 or 2:3:4. Pebbles from well-stratified limestones are slightly oblate, with the thickness-length ratio of 1:3 to 1:4, and in very rare instances even 1:5 to 1:6. These are usually not as well rounded and have an angular form.

Pebbles of sandstones, quartzites, and diorites have the same dimensions, form, and the degree of roundness as the limestone pebbles. Siliceous pebbles are not as well rounded, commonly of an angular isometric form and measuring 1, 2, or 3 cm.

The conglomerate contains a few layers of red calcareous sandstones and gravels, which establish its position.

The carbonate pebbles are represented chiefly by light-gray massive limestones, finely to very finely crystalline. Somewhat less common are gray, stratified, dense, fine-grained siliceous limestones. Only in a few places are there pebbles of light-gray organogenic-detrital limestones, dark-gray crystalline sparkling dolomites, and brown-red fine-grained limestones, in places with fragments of fauna. All these limestones are not metamorphosed and not schistose, as a rule. Only in a few places are there pebbles of a brecciated and slightly schistose rock.

The shattered zone conglomerate has a

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[3]Plasticheskiye deformatsii izvestnyakov v zonakh drobleniya, soprovozhdayushchikh krupnyye razlomy.

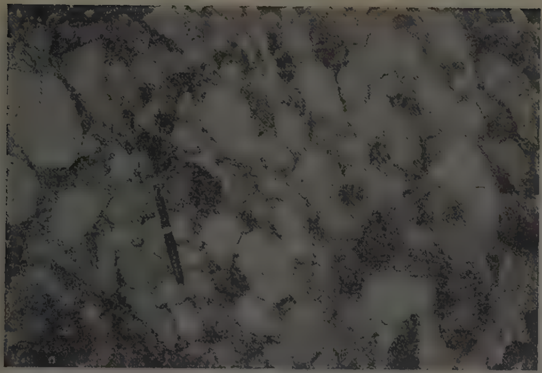

FIGURE 1. Conglomerate outside the shattered zone.

Light color: limestone pebbles; dark color: pebbles of other rocks.

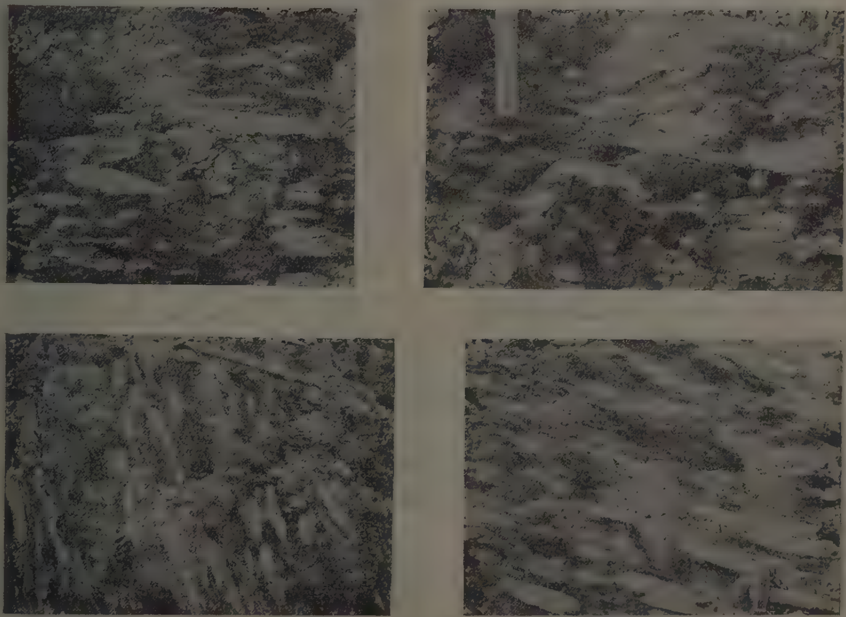

FIGURE 2. Conglomerate within the shattered zone.

Light color: limestone pebbles; dark color: pebbles of other rocks.

different structure (Figs. 2, 3). It is made up of pebbles of the same composition; the pebbles, however, have been deformed and have a somewhat different structure. The deformation of limestone pebbles is of a plastic character: they are not fractured but rather

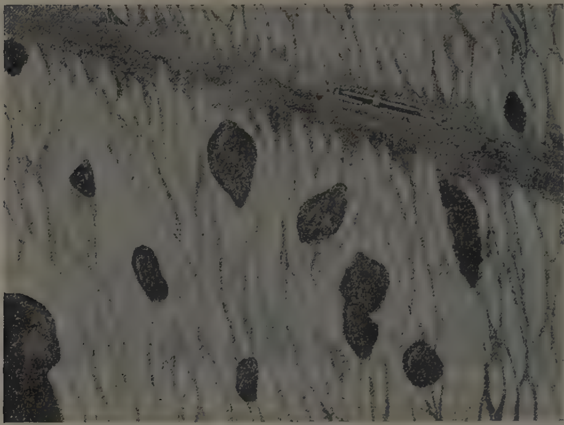

FIGURE 3. Conglomerate structure within the shattered zone.

White: limestone pebbles; black: pebbles of other rocks; gray: sandstone layer and the conglomerate cement.

strongly flattened to thin lenses (Figs. 2, 3, 4). Pebbles of sandstones, diorites, and siliceous rocks, on the other hand, maintain their form or else are broken by fractures accompanied by slight shifts. As a result, the conglomerate has acquired an augen structure: the flattened limestone pebbles appear to flow about the remaining rounded pebbles of sandstones, diorites, and siliceous rocks, as well as about isolated not quite deformed limestone pebbles (Fig. 3).

The limestone pebbles, flattened to lenses, usually have sharp, tapering edges. Their oblateness is uneven, from very fine lenses to some almost intact pebbles, with every shape in between; the strongly deformed pebbles much more abundant than the slightly deformed ones. The average thickness-length ratio for lenticular pebbles is 1:8, with 1:15 in strongly schistose segments. Slight plication is observed where the pebbles have been squeezed very thin.

The pebbles are extended parallel to the fault strike and oriented at a steep angle to the stratification. Thus, in one of the exposures, the schistosity strike and the elongation direction of the pebbles are S 70° E with a southwesterly dip of 62°, although the stratification strike is S 15° E, with a southwesterly dip of 14°. The lack of coincidence in the schistosity and the orientation of flattened pebbles with the bedding is especially noticeable when sandstone layers are present in the conglomerate. In that event, the flattened pebbles are seen to penetrate the sandstone layer (Fig. 3).

The limestone structure in flattened pebbles is also different from that in intact pebbles outside the shattering zone. In flattened pebbles, the limestones have been recrystallized, with a clean-cut schistosity parallel to the elongation of the pebbles. Their characteristic lenticular, schistose, and knotty-schistose structures have been determined by the elongation and parallel orientation of calcite grains and commonly by a flow structure of fine-grained aggregates about coarser grains. However, the recrystallization of the rock is not too intense, allowing one to discern all varieties of limestones present in intact pebbles.

The following conclusions follow from all these data on the structure and relationship of limestone pebbles in nondeformed and deformed pebbles:

1. Stresses in the shattered zone were sufficient to cause plastic deformations in limestone, under the temperature, chemical, and other conditions prevailing there.

2. Under those conditions, the limestone deformation was expressed in compression in one direction, and in spreading in two other directions, normal to the first. The limestone flowed as a plastic mass under a one-sided pressure. In the process, it developed schistosity normal to the compressing stresses; its texture, however, changed but little.

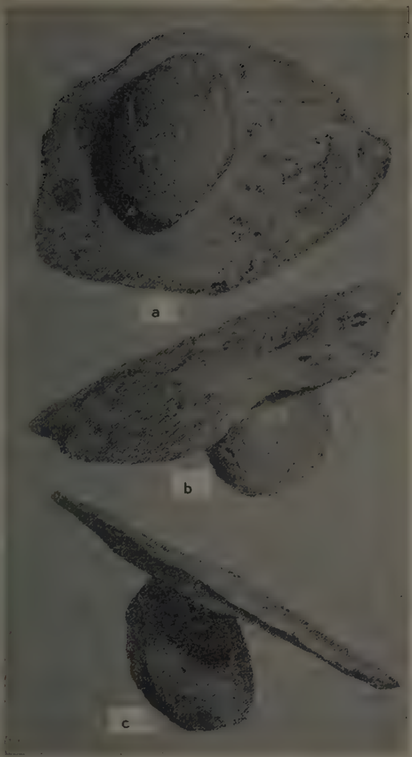

FIGURE 4. Flattened limestone pebbles from conglomerate within the shattered zone, and a not quite deformed pebble of the same weight and composition, from conglomerate outside it.
Photographs of the same sample (a) have been taken from three sides, reduced 2X. Notice the relationship in the size and shape of the pebbles, also the sharpened edges (c) and the slight contortion (b) of the flattened lenticular pebble.

3. The pebbles have been thinned 4 to 5 times, in the direction of the stress, and have been elongated correspondingly, 2 to 2.2 times, in two directions normal to it.

Applying these conclusions to large limestone blocks caught in the shattered zones accompanying faults, it readily follows that limestones would undergo plastic deformation, wherein they are strongly compressed until they flow along the fault zone in schistose lenses. Considering that zones of shattering often are several hundred meters wide, cutting the limestones along a distance of many kilometers, it is natural to anticipate the presence of limestone lenses in the fault zone, several kilometers away from where it crosses the limestones. Just such a picture has been observed in localities along the Akbastau and Aksoran-Akzhal'sk fault zone, with lenses of schistose and recrystallized limestones, caught among utterly unrelated rocks, as far away as 15 to 20 km from where the fault cuts the limestones. These lenses appear to have originated as a result of limestone flow (penetration) along the fault, as a plastic response to the tectonic stresses within it. Of the same nature is the very strong deformation of faunal remains in some of the lenses and the lenticular, schistose, and knotty-schistose rock structure, similar to that in the analyzed pebbles.

Thus, both small and large limestone bodies undergo plastid deformation when subjected to powerful stresses originating in the process of formation of major faults.

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NEW DATA ON MESOZOIC BAUXITES DISCOVERED ON THE EASTERN SLOPE OF THE SOUTHERN URALS[4]

by

P.I. Nozdrin

In 1956, two beds of bauxite, separated by clays, were penetrated by borehole No. 11, at 11.0 to 24.0 m, in the area of quadrangle 40-XXXV.

Borehole No. 11 is located in the valley of the Krutoy Spring, which flows into the Ural, on the latter's right bank, between the villages of Pokrovskoye to the north and Orlovskoye to the south.

Exploratory drilling in an area of about 1 km^2 has revealed that bauxites apparently occur in karst holes or in depressions. The bedrock is represented by lower Carboniferous limestones. As revealed by spore-pollen analyses, unconsolidated deposits in the depressions are represented by the Cretaceous, in their lower part; and by the Tertiary and Quaternary, in the upper.

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[4] Novyye dannyye o nakhozhdenii mezozoyskikh boksitov na vostochnom sklone yuzhnogo urala.

Table 1

Results of chemical analyses of samples from borehole No. 11

Sample No.	Depth (m)	Components in material dried at 105°C (%)									
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	MnO	P_2O_5	Loss in heating	Total
23	9,0—11,0	50,80	14,36	7,47	1,26	10,48	2,64	0,17	0,11	12,44	92,72
24	11,0—12,0	5,37	25,04	35,88	12,76	2,28	0,36	0,03	0 03	18,07	99,82
25	12,0—13,0	3,94	27,06	42,97	8,32	0,56	0,36	0,04	0,05	16,97	100,27
26	13,0—13,2	3,91	24,93	50,05	1,26	0,80	0,18	0,05	0,13	18,16	99,47
27	13,2—15,0	33,98	26,13	20,94	4,57	0,56	0,28	0,05	0,05	13,43	99,89
28	15,0—17,0	39,64	37,65	2,08	4,40	0,42	0,22	0,03	0,12	13,91	98,47
29	17,0—17,50	1,12	51,55	13,50	5.00	0,85	traces	traces	0,02	28,66	100,70
30	17,50—19,20	6,90	24,51	41,75	6,70	1,59	0,29	0,05	0,06	17,42	99,27
31	19,20—20,20	2,19	28,62	35,30	5,49	6,45	0,40	0,03	0,03	21,60	100,11
32	20,20—22,40	3,78	28,84	43,86	3,84	0,86	traces	0,02	0,05	19,26	100,51
33	22,40—24,0	7,95	41,59	24,88	2,65	0,71	0,11	traces	0,05	22,46	100,41
34	27,0—28,6	14,32	13,57	57,73	1,30	0,71	0,25	0,03	0,05	11,84	99,80

NOTE: Comma represents decimal point.

The limestone area is in a meridionally trending fault contact with Silurian and Devonian extrusive and tuffaceous sedimentary formations which are developed west of the contact.

The geology of this region is very similar to that of the Taldyk-Ashchesay bauxite deposit, 330 km southeast of the Krutoy Spring.

In 1956 another bauxite occurrence was discovered 12 km south of the Krutoy Spring. It is located in the northern part of quadrangle M-40-V, directly south of quadrangle 40-XXXV. An accumulation of 18 to 20 blocks of bauxite rock, measuring 70 x 70 x 30 cm, was found in a dry hollow on the left side of the lower Orlovka, a right tributary of the Ural River. A chemical analysis of one of the blocks revealed the following composition in percentages: SiO_2 - 0.45; Al_2O_3 - 42.79; Fe_2O_3 - 26.07; TiO_2 - 3.68; CaO - 0.90;

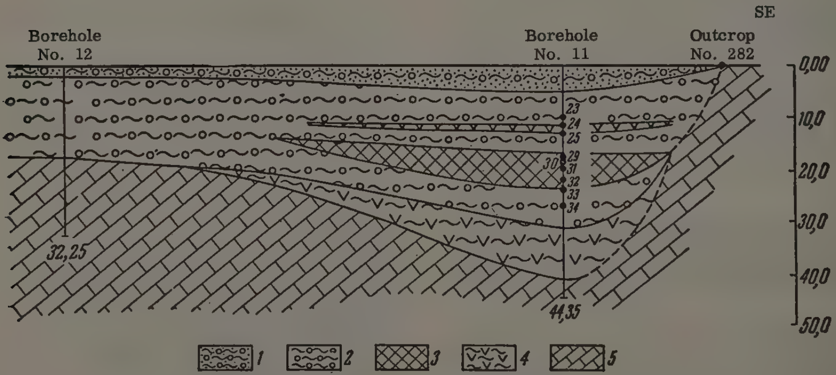

FIGURE 1. Diagrammatic cross section of the Krutoy area, from data of boreholes 11 and 12.

1 -- Arenaceous-argillaceous pebble deposits; 2 -- clays with nodules of brown iron ore; 3 -- argillaceous bauxite with nodules of hard bauxite; 4 -- redeposited weathering products of extrusives; 5 -- bituminous limestones.

P_2O_5 - 0.03; loss in heating - 23.42%. Bedrock here is early Carboniferous limestones.

A geologic environment similar to that of this region is found in the area between the Magnitogorsk latitude on the north and that of Orsk on the south, where it is characterized by an upper Paleozoic basement of lower Carboniferous limestones and calcareous rocks in a regional fault contact with Silurian and Devonian rocks which, over most of the area, are covered by unconsolidated deposits. Discovery of additional bauxites by detailed prospecting, should not be ruled out for this area.

The discovery of Mesozoic bauxites on the eastern slope of the southern Urals, similar to the known Mesozoic deposits of the middle Urals, northwestern Kazakhstan, and the Turgai trough, is definitely interesting.

Our findings suggest the need for a careful study of unconsolidated deposits developed on lower Carboniferous carbonate rocks of the southern Urals eastern slope, for the bauxite deposits they may contain. Priority in such prospecting should be given to the belt of carbonate deposits extending from Magnitogorsk to Orsk, and possibly farther north and south of these points. This belt might contain local depressions with bauxite deposits.

South Urals Geological Administration
Ministry of Geology
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Ufa

STYLOLITES IN THE VOLGA REGION[5]

by

F.F. Rybakov

Stylolites are bizarre formations associated exclusively with sedimentary rocks. Their peculiar form has long attracted the attention of many investigators.

In 1751, Milius wrote that stylolites were petrified trees, and 56 years later, Freusleben voiced an opinion that they represent a serrate structure of "fletz" limestone. Later on, stylolites were described as fossils, lignoliths, epsomites, crystallites, "crow feet," "finger nails," "bedding sutures," etc.

The investigators have also tried to explain the origin of stylolites. One school of thought ascribed to them an organic origin; the other held that they had been formed by recrystallization, as an effect of pressure or of solution. All these theories, however, were hypothetical, without a reliable factual basis and only of an incidental character in their explanation of the purely morphologic features of stylolites.

The wide distribution of stylolites, their association with most diversified stratigraphic layers, has led many students to the idea of their random distribution devoid of any geologic regularity.

In this paper, stylolites are regarded as a result of definite geologic processes, as an evidence of definite facies and paleogeographic conditions, and as an element of rhythmic sedimentation.

Stylolites present columnar or conelike formations, rectilinear or curved in outline, and made up of the same rocks in which they occur. They vary very strongly in cross section -- from circular to regular pentagonal and hexagonal with sides more or less serrate, diameter from 2 mm to 12 cm, most commonly 5 to 30 mm, and height from 1 mm to 25 cm.

In their axial section, stylolites present a suture line, commonly called a sutural seam. These sutural seams vary in shape (from roughly dentate to almost smooth or slightly wavy), distribution, and structure. The contact surfaces of stylolites are usually covered with a fine bloom of greenish to dark-green crust of strongly calcareous clay. The axial section plane presents what look like a complex of microcolumnar partings. In horizontal forms, this section plane is smooth.

The prevailing opinion, as reflected in the literature, is that stylolites are usually normal to the bedding and faulting planes and that they tend to assume a vertical position, even in inclined beds. The data on hand disclose that there are vertical, inclined, and horizontal stylolites, with the first type predominating and the other two considerably less common.

Horizontal stylolites differ from vertical ones in their lack of the crust or bloom of dark to greenish calcareous clays. Instead, their corrugated surface is covered, as it is in the vertical stylolites, with a dark to grayish bloom of clay substance.

Paleozoic sediments of the middle Volga region carry diversified forms of stylolites, corresponding to different beds. Their rectilinear corrugated surface is formed by both sharp and blunt ribs, either smooth or rough

[5] Stilolitovyye obrazovaniya povolzh'ya.

and uneven (in horizontal stylolites).

The lower end of vertical and inclined stylolites is always tipped with a "cap" of dark, greenish, or dark-green calcareous clay. The area of the cap is, as a rule, proportionate to the size of the stylolite, more exactly to its surface: the greater the area and height of the stylolite, the greater the area and the thickness of its clay cap. The lower boundary of a stylolite horizon is mostly uneven, locally spiny, with thorn-like projections tipped with clay caps.

The chemical composition of clay caps, crusts, and blooms on the corrugated surface of stylolites is generally the same; the thickness of caps is from fractions of a millimeter to 1.5 cm.

Stylolites are accompanied, as a rule, by intercalations of greenish clays, from several millimeters to 80 cm thick. These intercalations occur over comparatively smooth surfaces of stylolite-carrying rocks.

Both stylolites and the associated intercalations of greenish to dark-green clays are comparatively widespread; they occur in almost every stratigraphic layer of the Paleozoic.

Their distribution along the strike is dependent on the homogeneity and lithologic consistency of the bed. Where a bed changes frequently, along the strike, to a different lithology, or even to a different facies of the same rock, the number of stylolites in the bed drops sharply, in places to zero.

As mentioned above, stylolite formations are associated with clay intercalations; the latter, however, occur in the absence of the former. It follows that the Paleozoic section carries more clay intercalations than stylolite beds. The distribution of stylolites over the bed is uneven and discontinuous.

Stylolite formations are best known from upper Carboniferous and Permian deposits. In the upper Carboniferous, they occur throughout the entire section.

In the Triticites interval of the Gzhel'skiy stage, stylolites are developed exclusively in carbonate rocks. In one of the core holes, they were found at the limestone-dolomite boundary, associated with the base of the limestones. The stylolites were 6 to 8 cm long, tipped with clay caps.

The limestone-dolomite boundary also is marked by thin calcareous greenish clays. In other core holes, stylolites were observed in tabular, slightly argillaceous limestones.

In the middle part of the Samara Bend (Samarskaya Luka) Triticites interval, stylolites are associated chiefly with algal limestones. They are more numerous in the eastern than in the western part. In the upper Triticites interval, stylolites are more abundant and better developed than in the two lower ones. They are especially conspicuous in nodular-algal limestones, known as "bear rock" among the local geologists. Stylolite formations of the "bear rock" are well exposed in the Staraya Zhila (Old Vein) quarry, near the mouth of the Sok River; in the Krestovoy ravine; and in other Samara Bend localities.

The lithologic section of the Staraya Zhila quarry is as follows, reading upward:

1. Dolomites, gray to dark gray, siliceous; 0.40 m thick.

2. Algal dolomites, strongly recrystallized; about 2 m.

3. Calcareous greenish clay intercalation, few millimeters to several centimeters thick.

4. Nodular algal limestones -- "bear rock," with stylolites developed on top and at base. Two stylolite stages are present at the base, with the lower associated with a spotty limestone, about 20 cm thick. Accordingly, it is somewhat different lithologically from the overlying gray "bear rock" limestone. On the whole, it is a single bed. The two lower stylolite stages are separated by thin calcareous clay. The clay caps are especially characteristic for first and third stages, with the second (inner) stage carrying thinner caps.

5. Greenish, plastic clays, locally slightly stratified; 2 to 5 cm thick.

6. Fusulina limestones.

The "bear rock" limestone makes a facies change in the western part of the Samara Bend, where stylolites almost disappear whereas the greenish clay intercalation is considerably thicker.

Stylolites reappear in the southern part of the Samara Bend but here they are very small. The stylolite-carrying rocks are represented by slightly calcareous, dense limestones with a comparatively diversified assemblage of minerals.

Minerals of both light and heavy fractions are unevenly distributed throughout the beds. The clastic material content is higher at the top and base of beds, with the heavy fraction predominating (pyrite, zircon, tourmaline, sphene), whereas the light fraction minerals predominate in the middle part (muscovite, chalcedony, feldspars).

Depth (m)	SiO_2	Fe_2O_3	FeO	Al_2O_3	TiO_2	CaO	MgO	SO_3	Na_2O+K_2O
264,60	20,3	0,89	1,16	9,36	0,2	24,60	10,7	2,25	0,87
264,75	24,5	1,76	0,74	8,71	0,29	18,90	12,2	0,72	2,4
264,80	40,2	2,2	0,6	15,05	0,37	11,30	8,1	2,05	1,12
265,0	16,3	1,23	0,37	5,5	0,25	24,20	15,0	0,82	1,1
265,15	36 6	2,0	0,74	11,1	1,45	13,50	8,96	0,85	1,2
265,30	4,5	1,5	0 44	0,46	0,13	50,50	0,52	2,6	0 49
270,45	35,6	2,6	0,70	8,5	0,25	22,9	0,52	3,75	2,2
270,55	50,1	0,94	0,74	22,6	0,30	6,5	3,70	1,20	1,7
260,65	51,0	2,0	0,70	24,4	0,33	5,8	3,54	2,38	1,5

Note: Comma represents decimal point.

The chemical analysis of stylolite-carrying limestones is given above.

These data show that stylolites were formed not in a homogenous carbonate body but in limestones or dolomites enriched to some extent by terrigenous clastic material.

In the Pseudofusulina interval, stylolites occur in detrital, algal, tabular, slightly argillaceous limestones and dolomites. Here, too, stylolite beds are accompanied by intercalations of greenish to dark green calcareous clays. This interval carries, besides the common forms, cone-shaped stylolites, associated with the top and bottom of beds. As a result of leaching of the stylolites, their sites are marked by a gnarled surface with a multitude of microfunnels. Similar surfaces have been observed at the occurrence of cone-shaped stylolites.

In the Sakmara-Artinskiy beds, vertical stylolites are also associated with organic varieties of carbonate rocks. In one of the Baytuganskaya core holes, they were encountered at the top and at the base of strongly anhydritic coral limestones. Stylolites were formed here prior to the sulfatization. The upper and lower parts of coral limestones are somewhat enriched by terrigenous material.

In the Yakushkinsk terrace, stylolites occur, in addition to pure carbonate rocks, in strongly sulfatized dolomites with intercalations of pure gypsum, also in brecciated and oölitic dolomites. Here, the stylolites are small, 3 to 4 mm. In this variety of dolomites, the stylolite layer also includes the gypsum intercalations, with the same stylolite forms developed in both. The sulfate varieties of dolomites, too, are marked by a definite rhythm in sedimentation.

In Kungur deposits, horizontal stylolites have been observed along with the vertical. Such forms occur in calcareous-argillaceous dolomites of the Sadki area. Here, the dolomites are gray to grayish-green, microstratified and tabular. The tablets are smooth, frequently with a bloom of greenish clay. The fine clay intercalations produce a banded structure in the carbonate rock.

Horizontal stylolites do not carry clay caps.

In Upper Permian deposits, stylolites are most common in the Kazan stage carbonate rocks where they are characterized by the same type of distribution as in the upper Carboniferous and Lower Permian.

In the Moscow area, stylolites have been encountered in the Yelets Devonian spotty limestones, similar to those from the upper Carboniferous of the Samara Bend. It has been noted in the spotty limestones that the number of stylolites grows, whereas that of the green clay intercalations decreases with the intensity in the spottiness, and vice versa.

It appears that stylolites originated during the sedimentation, rather than as a result of some secondary processes. The secondary processes, such as leaching, took place after the formation of stylolites.

A stylolite layer is an element of a cycle, marking the latter's initial or terminal stage.

Rapidly changing sedimentary conditions, accompanied by an exposure or near-exposure of the sediments during the cycle, appear to have been most favorable for the stylolite formation.

Stylolite formation periods were short, with frequent breaks in sedimentation.

The multiplicity of stylolite forms is determined by differences in the cycle formation, on one hand; and by the peculiar change in facies, on the other.

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Received August 1, 1957

AGE OF PALEOZOIC DEPOSITS ON THE KOTEL'NYY ISLAND[6]

by

M.S. Zhizhina

In the fall of 1955, I received for identification a large collection of corals brought in that year from the Kotel'nyy Island by the geologists of the Scientific Research Institute of Arctic Geology, D.A. Vol'nov, D.S. Sorokov, and O.V. Cherkesov.

The Kotel'nyy coral fauna has been known since 1886 when it was first discovered by E.V. Toll', along with other fauna, on the east and northeast shore of that island.

All of that fauna (corals, brachiopods, trilobites, ostracods, etc.) was briefly described by E.V. Toll', in 1889 [3]. The age of the fauna, and consequently of the source deposits, was established as Silurian and Devonian.

A total of 18 coral forms, among them 6 Devonian, were described: Cyathophyllum caespitosum Goldf., C. hexagonum Goldf., Favosites (Pachypora) cervicornis Blainv., Alveolites suborbicularis Lam., Aulopora serpens Goldf., Syringopora sp., and 12 Silurian: Favosites gothlandica Lam., F. forbesi Edw. et Haime, Alveolites labechei Edw. et Haime, Columnaria alveolata Goldf., Heliolites interstinctus Lam., Halysites catenularia Linne, H. parallela Schmidt, H. keyserlingi sp. nov, Palaerea lopatini Lindst., Cyrtophyllum densum Lindst., Syringopora sp. Nov., S. sp.

On the basis of that fauna, E.V. Toll' [2, 3] believed that chiefly lower Upper Silurian (Llandoverian) and Middle Devonian rocks were present on that island. As a matter of fact, even on the basis of the above roster of corals, it can be stated that Wenlockian deposits are present along with the Llandoverian in the Kotel'nyy Silurian. In addition, older Upper Ordovician deposits undoubtedly are developed there.

The presence of Upper Ordovician deposits is substantiated by the occurrence of such corals as Tollina (Halysites) keyserlingi (Toll) and Cyrtophyllum densum Lindst., which have been since established as index Upper Ordovician forms.

The presence of Wenlockian or younger deposits is suggested by the occurrence of Favosites forbesi Edwards and Haime.

The new faunal collections are of great interest, being richer in numbers and variety. They establish the presence on the Kotel'nyy of a considerable number of hitherto unrecognized Upper Ordovician deposits [1, 2] and they differentiate Silurian deposits into Llandoverian-Wenlockian, Wenlockian-Ludlowian, and Ludlowian.

According to D.A. Vol'nov, D.S. Sorokov, and O.V. Cherkesov, the coral fauna was collected from many limestone exposures, chiefly in basins of the Diring-Ayyan, Malyy Diring-Ayyan, Sannikova, and Reshetnikova Rivers, in the northeastern part of the island. Similar deposits, not as well developed, are present along the middle course of the Khos-Teryutteekh River and the upper reaches of the Chekurka, near the west coast where corals were also collected.

Corals are most numerous in the Diringayan[7] formation, the lowest in the stratigraphic section of that area. No corals have been found in the lower part of the formation. In the middle part, made up of thick-bedded massive limestones interbedding with medium-thick limestones, corals are present chiefly in thin limestones. Identified from there are: Palaeofavosites sp., Calapoecia canadensis Billings, Paleohalysites tollinoides Zhizhina, P. delicatulus Wilson, P. sp. nov., Tollina elegantula sp. nov., T. compacta sp. nov., T. sp., Cyrtophyllum orthis Sokolov, C. aff. densum Lindst., C. ex gr. lambeiformis Sok., C. sp. nov., Propora sp. nov. and others.

This faunal assemblage is similar to the oldest Late Ordovician coral assemblage from the Taimyr Peninsula Paleozoic, judging by the presence of such forms as Calapoecia canadensis Bill., Paleohalysites tollinoides Zhizh., P. delicatulus Wilson, and several species of Tollina and Cyrtophyllum. Many of these species, such as Calapoecia canadensis Bill. and Paleohalysites delicatulus, are known from the Upper Ordovician of the Urals; Cyrtophyllum orthis Sok. and other species of this genus, from the western part of the Siberian platform and from the Upper Ordovician of Canada, North America, and Arctic regions of these and other areas [4].

The Late Ordovician age of this coral assemblage is undoubted, because these species are almost completely missing in the overlying Llandoverian and underlying Middle Ordovician. An exception is Calapoecia canadensis Bill. which occurs in both the Lower and Middle Ordovician.

[6] K voprosu o vozraste paleozoyskikh otlozheniy na ostrove kotel'nom.

[7] The names of this and other formations are after D. A. Vol'nov, D.S. Sorokov, and O.V. Cherkasov, 1955.

On the basis of these data, the middle part of the Kotel'nyy Island Diringayan formation, too, is undoubtedly Upper Ordovician.

The overlying limestones, assigned to higher Diringayan beds and to the still higher Sulbut formation, carry a quite different, Silurian coral assemblage.

The following forms have been collected from massive thick-bedded limestones resting on beds with an Ordovician fauna, in different exposures: Paleofavosites ex gr. alveolaris (Goldf.), P. aff. balticus (Rukhin), P. sp. sp., Mesofavosites (?) sp., Multisolenia cf. tortuosa Fritz, Favosites cf. gothlandicus Lam., F. sp sp., Paleohalysites gothlandicus (Yabe), P. aff. parallelus Schmidt, P. sp. sp., Syringopora sp.

These limestones are most likely Llandoverian, although the presence of Multisolenia cf. tortuosa Fritz might suggest the Wenlockian, since it is common for that time, in many regions. It is rare in Llandoverian deposits.

The overlying Sulbut formation is made up of rapidly weathering pure and dolomitic limestones, rarely occurring in outcrops. Corals are very rare in this formation, with Favosites forbesi Edwards and Haime var. multiperforata Tchen., F. ex. gr. forbesi Edwards and Haime and F. sp. sp. occurring in gnarly massive to medium-tabular limestones. The beds with such a fauna may be assigned to the Wenlockian-Ludlowian.

Brown-gray to gray massive to medium-tabular gnarly limestones with Favosites (Dictyofavosites) sp. nov. F. aff. russanovi Tchen., and F. ex. gr. gothlandicus Lam. (identified by M.A. Smirnova), probably belong to the Ludlowian stage.

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REVIEWS AND DISCUSSIONS[1]

YE. A. SHCHERIK'S BOOK "STRATIGRAPHY AND FACIES OF TERTIARY DEPOSITS OF NORTHWESTERN CAUCASUS AND WESTERN CIS-CAUCASUS"[2, 3]

by

V. A. Grossgeym

Since the publication in 1939 of the "Stratigraphy of the U. S. S. R.," vol. XII, there has been nothing new on the Neogene stratigraphy of the southern U. S. S. R. A Paleogene correlation for that region is altogether lacking, except for regional reviews in the published volumes of "Geology of the U. S. S. R." Many new data, not even partially published, have been gathered since that time, as a result of stratigraphic control- and exploration drilling.

For this reason, any new publication on Tertiary stratigraphy of a major province is of obvious interest. And so we were very much interested in the recently published Ye. A. Shcherik summary of Tertiary stratigraphy of the northwestern Caucasus and western Cis-Caucasus. A brief acquaintance, however, with this work brings disappointment, and more familiarity brings the realization that it is not up to expectations.

The main shortcomings of this work are as follows: it is poorly arranged; its stratigraphic outline is unfounded, with its subdivisions inadequately substantiated; there are no appropriate illustrations such as facies maps or even an index map; the descriptions are careless, with many errors of fact including a number of contradictions.

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[1]Kritika i diskussii.

[2]O knige Ye. A. Shcherik "Stratigrafiya i fatsii tretichnykh otlozheniy severo-zapadnogo kavkaza i Zapadnogo Predkavkaz'ya.

[3]Trudy Sces. Nauchn.-Issled. Geologorazved. Neft. Inst (VNIGNI). Gos. Top. Tekh. Izd., 1957.

The author has presented her material in a series of descriptions of deposits, according to their subdivisions, but the latter are only postulated, without any justification by either old data or by those of the author.

In order to get an idea of a section and of the reasons for its differentiation, the reader has to look for its components in different chapters. As a result, some intervals are not described at all, and it is difficult to judge a section as a whole, with its breaks and unconformities.

There are no faunal descriptions for the subdivisions. The sections are arranged by river basins, without any attempt at differentiation by facies-tectonic zones. A single artificial stratigraphic scheme is made to fit the entire immense area, although it is clear even from the author's descriptions that the degree of differentiation is not the same in all facies zones.

Some of the specific inconsistencies and errors are given below.

As early as the introduction, the author states that "Paleogene foraminiferal fauna is represented chiefly by a group of arenaceous forms, fairly poor in their facies composition." A few lines below, we read that "Eocene marls underlying the Maikop formation carry a diversified foraminiferal fauna."

Ye. A. Shcherik ascribes to N. B. Vassoyevich the uniting of the Abaza horizon and the above-mentioned Eocene formations into a single foraminiferal series. The fact is that the Abaza horizon was separated in the western Kuban' section (Pshish River) by S. T. Korotkov, several years after. There is no adequate substantiation for the age of the beds which Ye. A. Shcherik assigns to the Abaza horizon, both in the introduction and in the text. These beds are indeed Paleocene; but that should have been shown by faunal evidence and not just by stating that "the Abazinsk horizon differs strongly from that sequence, lithologically and its quite different

foraminiferal fauna" (p. 3). We found Cucculea (type C. volgensis Arkh.) in the upper II' formation from the Zybza Basin, which is what has determined its Paleocene age. In her references, Ye. A. Shcherik, for some reason, omitted that fact (Grossgeym, V. A., Paleogene Section in the Zyzba Basin. Tr. VNIGNI, vyp. 4, 1954) and only gave the foraminifera list (p. 28).

We quote the following statement on the age of the El'burgan horizon: "From an analysis of the sedimentary conditions of the El'burgan and adjacent horizons, and considering its fauna, we are inclined to share the opinion of many students who assign it to the lower Paleocene" (p. 5). Just how the sedimentary conditions can help in determining the El'burgan's age is not explained. (Parenthetically, the El'burgan formation, in the western Kuban' region, is both underlain and overlain by flysch deposits). There is no faunal description, either here or for other basins (with the exception of Afips and Shebsh Rivers), although the El'burgan formation is known from many sections (Anapa, Il', Ubin, Psekups Rivers, etc.).

It is very difficult to understand, just what part of the Anapa section Ye. A. Shcherik did assign to her El'burgan horizon. (It should be noted that she calls "horizons" all of the subdivisions of a stratigraphic section, although some of them are several hundred meters thick; the use of the term "horizon" for "formation" has long since been abandoned). Her description of it on page 5 is equally applicable to the underlying beds. For some reason, the fauna roster and any reference to earlier authors are omitted (this is very characteristic of the entire work).

As a rule, no fauna rosters are given in descriptions of sections along the Bakanka, Shibik, Abin, Ubin Rivers of the Apsheronsk-Khadyzhensk area, and others. Only, in a few places, a few arenaceous foraminifera are mentioned (Malyy Zelenchuk River), and only those listed first in the systematic rosters; and the leading planktonic foraminifera -- at the end of such rosters -- are omitted altogether.

The formation thicknesses, as mentioned, are not true. The El'burgan (Tsitse formation) along the Bakanka River is 350 m and not 90 m; along the Shibik River, 400 m instead of 115 m; and 400 m instead of 100 m along the Abin (p. 6).

The age of the Goryachiy Klyuch formation is determined only by the reference to paleontologic data and by its stratigraphic position; it is stated that this formation "lies between the paleontologically defined lower Paleocene and middle Eocene." (p. 12). However, the author herself assigns the overlying Abaza horizon to the top of the Paleocene.

The differentiation of the Goryachiy Klyuch formation into three members, by their sand content, is valid only for the Goryachiy Klyuch and adjacent areas. Elsewhere, including the producing districts, it is represented by a monotonous flysch. Thus, the Goryachiy Klyuch formation cannot be differentiated by its sand content. It is differentiated instead into four members (by their lime content, the color of clays, and the radiolarian fauna) traceable from the Kura-Tsetse River to Anapa. All thicknesses of western Kuban' sections are cut almost in two, because the two upper members, as designated by ourselves (Kipyachaya ravine and Akhtyrskiy), have been assigned by Ye. A. Shcherik to the Abaza horizon.

Quite amazing is Ye. A. Shcherik's description of deposits which are not there. For instance, the Goryachiy Klyuch formation is missing along the Pshish River; nevertheless it is "described" on p. 19. The same is true for the Belaya River where the entire Paleocene is about 8 m thick, whereas Ye. A. Shcherik assigns to it 120 m (pp. 20, 29). The impression is given that the Goryachiy Klyuch formation is blanket from the Anapa to the Kuban' Rivers, whereas as a matter of fact it is missing at a number of points (Pshish, Tukha, Pshekha, Gubs Rivers, left bank of Laba, etc.).

Ye. A. Shcherik has the most trouble with the extent of the Abaza horizon. This name was assigned by K. A. Prokopov to clays with siliceous intercalations and marly lumps in the Malyy Zelenchuk Basin. Other students applied this term to a quite different type of sediments of the western Kuban' flysch zone, with various individuals working far away from each other applying it to different parts of the section. As a result, the term "Abaza formation: (or horizon) has lost all meaning as applied to western Kuban' sections, and had to be abandoned in a detailed stratigraphic study.

In western Kuban', beds contemporaneous with the eastern Kuban' Abaza are known as the Il' formation. They have been traced from the Pshish to Shibik Rivers, and west of there. The Il' formation is represented by an alternation of terrigenous flysch and concretion beds. According to Ye. A. Shcherik, this writer has subdivided the Abaza horizons of the basin of the Akhtyr' Rivers and Khabl'-Zybza into three "formations" (quotation marks by Ye. A. Shcherik). The fact is that I did not correlate those formations with the Abaza; I first left that question open,

then correlated the Abaza with the Il' formation, only (1955). Speaking of references, a book published at the end of 1957 should have reflected our final conclusions as of the beginning of 1955, especially when Ye. A. Shcherik did have time to include in her book the data from Novo-Titarovskaya, Slavyanskaya, and other areas drilled as late as 1956 (p. 143 ff).

As a result of such a cavalier treatment of other authors' data, Ye. A. Shcherik correlated deposits strongly differing in their stratigraphic extent. Thus she correlated the Il' formation (200 m), along with a considerable part of the Goryachiy Klyuch formation (members Kipyachaya ravine and Akhtyrskiy, total thickness of about 400 m) of the Akhtyrskiy-Bugundyr and Zybza areas -- which she called the Abaza horizon -- with the concretional bed of the Khadyzhensk area, which accounts for only a part (about two-thirds) of the Il' formation. The beds which S. T. Korotkov, in his time, named as the Abaza formation of the Pshish Basin, are partially described by Ye. A. Shcherik as a part of the Kutais formation (upper part, p. 37), whereas the bulk of them (terrigenous flysch) is missing altogether in her section. In the Adygeyskaya uplift, the thickness of the Abaza horizon is either exaggerated several times (along the Gubs River), or else this bed is described where it is missing, as along the Belaya River (Ye. A. Shcherik herself states on p. 169 that the Abaza horizon is missing there).

The next layer turns out to be Kutais, in which Ye. A. Shcherik has combined the Zybza and Kutais formations, differing both lithologically (the Zybza formation being a marly flysch, and the Kutais consists of calcareous clays), and paleontologically (Zybza forms: Globorotalia nartanensis Schutz, G. lensiformis Subb.,[4] G. subbotinae Moros; Kutais forms, G. aragonensis Nuttal and G. velasconensis Cushman). Her mentioning the fact that some paleontologists are confused between the Zybza and Kutais forms (p. 34) and that consequently these two formations should be combined, is without merit. If the lack of proper qualifications by individual paleontologists be taken for a general criterion, all attempts at a detailed differentiation of many sequences would have to be abandoned. Her reference to N. N. Subbotina who allegedly recognized a single microfaunal zone in the Kutais formation is erroneous. Recently (1955), the latter recognized a zone of globorotalia with an inconspicuous cone, in the Zybza formation. As usual, a lower Oecene age of the Kutais formation is proclaimed without a reference to any specific forms. This is not true. Only the Zybza formation is lower Eocene (incidentally, it was recognized as a separate unit, at the Conference for Stratigraphic Unification of the Southern U. S. S. R. Tertiary, in 1955), because the corresponding globorotalias occur along with the Iprskiy nummulites in the Crimea. This has been confirmed by the Conference. The Kutais formation, on the other hand, is middle Eocene, because Globorotalia aragonensis Nutall occurs at many points along with middle Eocene nummulites (Trialety, Crimea, Gubs River).

Even more odd is the assigning of the Kaluga formation to the lower Eocene, with a reference to its mollusc fauna. I. A. Korobkov, who described that fauna from the Kaluga formation (incidentally, an endemic fauna), has named his work, "Middle Eocene Molluscs of Northern Caucasus and Their Environment" (Uchenyye Zap. Leningr. Gos. Univ., No. 189, 1955).

Ye. A. Shcherik assigned the Khadyzhensk formation to the middle Eocene, mentioning the appearance of Hantkenina lehneri Cushman et Jones, Globigerinoides conglobatus Brady, etc., as one of the characteristics of that formation. These forms appear only at the very top of the Khadyzhensk formation (Kerestinsk bed), which is upper Eocene.

The Maikop beds are differentiated into the lower, middle, and upper Maikop. The boundary between the lower and middle Maikop is traced on the ostracod bed. This, however, has been done by only a few students and has no justification. Even the usual references to fauna are lacking, with the Maikop very poorly characterized faunistically. Not a single fish or diatom is identified, and there are almost no references to molluscs (for instance, for the Ol'ginskaya formation of the Kuban' River), etc.

In describing the Miocene deposits, Ye. A. Shcherik used some data on the central part of the west Kuban' downwarp. However, most references to those sections are incorrect in many respects. She states, for instance, that the Chokrak of the Anastasiyevka area is represented by dark gray, slightly calcareous clays with intercalations of marl and with a numerous Spirialis fauna. The fact is that no cores have been taken from that interval. The (electric) log reflects only the type of the rock but not its color or the lime content, let alone its fauna (p. 101).

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[4]This form occasionally strays into the base of the Kutais formation. Globorotalia aragonensis has indeed developed from G. lensiformis (more precisely, from G. nartanensis, a form with a closed umbilicus; G. lensiformis is an intermediate form). The entire biostratigraphy, however, is based on the evolution of the organic world.

The description of the Karagan section from the Slavyansk area, including its fauna, is utterly fantastic because the deepest well there did not go below the lower Sarmatian (p. 108).

In the Troitsk, Slavyansk, and Novo-Titarovskaya areas, the Meotis (uppermost Miocene) thickness is underestimated by a factor of 2 to 3 (p. 143).

Page 150 gives a description of the Pontian in the Novo-Dmitriyevskaya anticline, along with its fauna; again, no cores have been taken from the Pontian, at that locality.

In the Troitsk area, Ye. A. Shcherik separates three Pontian members: the lower, arenaceous-argillaceous; the middle, argillaceous; and the upper, arenaceous-argillaceous. As a matter of fact, sandy silts are developed only in the middle part of the section, with the lower and upper parts made up of clays (p. 153).

Above the Pontian, Ye. A. Shcherik places ore-bearing beds whose age she determines as late and middle Pliocene. The age of younger beds is not mentioned anywhere. As to the ore-bearing beds, their age (as of some of the overlying beds) is middle Pliocene. The late Pliocene opens, as is well known, with the Taman beds.

It is hard to see why the author deviated from the generally accepted differentiation of the Pliocene into Pontian, Cimmerian, Kuyal'nik, etc. For some reason, the Taman beds are called the Akchagyl'skiy stage.

The description of Tertiary deposits ends here. There is nothing said about the top of upper Pliocene (Krasnodarsk formation with Unio sturi), or on the Tertiary-Quaternary boundary.

Now for a few general remarks.

As already stated, there is no justification given for the age determination, except for some general considerations of Ye. A. Shcherik. Microfauna rosters are lacking nearly everywhere (this is especially important for the Paleogene where the findings are rare and therefore significant), or else they are abbreviated at the expense of index form. Those rosters that are given, especially for the Paleogene, are compiled carelessly and unsystematically; the synonyms are not checked, the species' authors are mixed up. For instance, on page 72, Lienenklaus is given in both the Lienen and Zienkes transcriptions. Representatives of the same genus are commonly given in different parts of the rosters, etc. In most instances, there is no reference to the paleontologists who did the identifying.

With the exception of V. Yevsyukova, there is no mention as to who did the petrographic analyses. Incidentally, there are hardly any references as to the sources of descriptions for most of the sections. In this connection, the bibliography at the end of the book contains hardly a fifth of the published or manuscript material on the Tertiary of the area in question. Ye. A. Shcherik apparently is not too well acquainted with geography, especially that of the Adygey uplift. The Belaya River section is described first, then that of the Laba, and then that of the Gubs River which flows between them (pp. 19-20); or of the Kurdzhips and Gubs Rivers first, then of the Fars River between them (p. 5), etc.

It is quite understandable that the concluding chapter (paleogeographic features and sedimentary conditions of the Tertiary basin), based on such incomplete stratigraphic material cannot contain a correct conclusion as to the sedimentary history of Tertiary basins (and not a basin, as the author states).

The author gives very little attention to the facies zonation. Suffice it to say that there is not a single facies map in the text. Nor does Ye. A. Shcherik tell anything about the differentiation into dry land and basins. The reader is left in the dark, for instance, as to where the lower Paleocene flysch was deposited. "In the western and central parts of the area in question," says the author (p. 168). However, the central part of the area falls in the vicinity of Timashevskaya and Vyselkovskaya stanitsas, i. e., on the platform slope of the west Kuban' downwarp. The reference to a southerly (sic!) migration of the flysch downwarp, in the middle Eocene, is incorrect, because of an interior uplift in that direction. The fact is that the flysch deposition had ceased by that time.

There are no silicified argillaceous deposits (opoks) in the Kutais formation. The Kaluga-formation rocks are more calcareous than the rocks underlying them, and not the other way around, as Ye. A. Shcherik states (pp. 169-170). A transgressive occurrence of the Kaluga formation has been observed only on the anticlinal apices of the western Kuban' region, and not everywhere as the author states (p. 170).

The same page has it that "a further equalization in the tectonic conditions of an open, comparatively deep sea took place in the Kuma time, throughout the northwestern Caucasus" (Italics mine, both here and below. Incidentally, there are geotectonic conditions of land but not of sea. V. G.). A few lines farther on, we read, "In the Beloglinskoye time, the basin, as a whole, underwent a

deepening." Still farther on, "The character of the sediments themselves and of their fauna suggests that the sedimentary conditions of the Beloglinskoye Basin correspond to those of a comparatively shallow sea, with a normal salinity." This is an obvious inconsistency.

The Maikopian time witnessed an intensive growth of anticlines, in the western Kuban', and not the formation of comparatively large downwarps, as the author believes (p. 171).

In describing the Chokrak Basin, Ye. A. Shcherik says not a word of the sharp curtailment in its size. Nor does she mention the Meotian Transgression in the western Kuban'. The disregard for geography, in many places, renders the text difficult to understand. Thus, it is stated on the subject of the Pontian, "In the central part (of what?), the area of the supposed dry land advances (where?), as witness the character of the sediments" (p. 176). The statement that the sand content increases westward in the Pontian western Kuban' downwarp is not true. On the contrary, the sediments grow more argillaceous, in that direction (p. 176).

The most fantastic is the general conclusion, on the last page. It reads: "It appears from the above exposition that the source of Tertiary sediments in the northwestern Caucasus marine basin . . . was a land in its southern part, somewhat to the north of the present Tertiary outcrops" (p. 177). Such a conclusion does not follow even from that incomplete and often incorrect material which the author has presented. It means that the land was not within the greater Caucasus mega-anticlinorium but in the central part of the western Kuban' foredeep, explored by a fairly dense network of boreholes. This is a province of the maximum Neogene (and Oligocene?) submergence, where the sediments are the thickest and the Neogene section uninterrupted.

We could go on citing ad infinitum the errors which abound in this work, on every page and sometimes in every paragraph. However, the instances cited are enough to expose the major shortcoming of the work under review, and to demonstrate its unsuitability as a reference or for any other practical purposes. It is a step backward in our concepts of Tertiary stratigraphy for the northwestern Caucasus and Cis-Caucasus.

The question arises, in this connection, as to how such a work came to be published. The names of the institution (VNIGNI), of the publishing house (Gos. Top. Tekh. Izdat.), and of the editor (B. P. Zhizhchenko) are given on the title page. The role of the editor is quite incomprehensible: it was his job to correct many of the above-named errors (fauna rosters, geography, etc.). One would think that the editor did not even read the manuscript, because many of the errors are elementary and much of the content is in opposition to B. P. Zhizhchenko's own views (such as on the stratigraphy of the Maikop beds, etc.). He could have mentioned this fact in footnotes or in the editor's foreword (which is also missing).

The scientific institution and the printing house, which have published this book, ought to pay more attention to the quality of their product than they did to Ye. A. Shcherik's book.

PHENOMENA AT CONTACTS OF VEIN GRANITES AND SKARN-MINERALIZED FORMATIONS IN THE SHEREGESH ORE DEPOSITS, GORNAYA SHORIYA[5]

(Critical observations on the V. A. Vakhrushev paper)[6]

by

V. G. Korel'

Issue No. 5, 1955, of "Izvestiya of Academy of Sciences U. S. S. R., Geologic series" carries a paper by V. A. Vakhrushev. We would have no objections if the author had confined himself to a description of "the peculiar contact reaction phenomena between skarn-mineralized rocks (contact-metasomatic formations, by themselves) and the pegmatoid granitoid and pegmatite-aplite veins cutting them," instead of regarding them as a proof of a younger (than the mineralization) age of the Sarlyk massif granites. However, V. A. Vakhrushev believes that his study has revealed the following new facts suggesting a younger age of the Sarlyk granites, as compared with the Sheregesh skarns: 1) the presence of magnetite ore xenoliths and skarn rocks in the near-contact zone of the granite massif; 2) a sufficiently broad development of vein granites which cut the skarn-ore bodies of the deposit.

Our contention is: 1) the presence of xenoliths of skarns and ores in the near-contact

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[5]Kontaktovo-reaktsionnyye yavleniya mezhdu zhil'nymi granitami i skarnovo-rudnymi obrazovaniyami na sheregeshevskom mestorozhdenii v gornoy shorii.

[6]With the publication of V. G. Korel's critical observations on the V. A. Vakhrushev paper (Izvestiya, No. 5, 1956), the editors consider additional discussion of the topic as serving no useful purpose, pending new substantiated data.

zone of the granite massif; 2) a sufficiently broad development of vein granites which cut the skarn-ore bodies of the deposit.

Our contention is: 1) the presence of xenoliths of skarns and ores in the near-contact zone of the Sarlyk massif, along with the cutting of such bodies by veins of pegmatoid granites and pegmatite-aplites, has been long known from that deposit, and was not discovered by V. A. Vakhrushev; 2) the fact that pegmatoid granite and pegmatite-aplite veins do cut the skarn-mineralized rocks, and that there are contact-metasomatic reactions between them, does not indicate a younger age of the Sarlyk massif; 3) biotitization, amphibolitization, and pyrrhotitization are indeed metamorphic phenomena (the author doubts that, citing certain deposits of the Tle'bes iron ore area), and biotite, amphibole, and pyrrhotite of those deposits are also contact-metamorphic and pneumatolytic minerals.

1. The fact that the Sheregesh skarns are cut by veins of pegmatoid granitoids and pegmatite-aplites has been known since the publication of N. A. Batov's work [1]. It was mentioned in our own candidate's thesis (1951), in that of A. G. Volodin (1952), and in a number of geologic reports in the libraries of geological organizations of western Siberia. Moreover, V. A. Vakhrushev had access to the rock collection and drawings of the Gorno-Shorsk expedition. It is not an accident, therefore, that his photograph (Fig. 2) of a piece of core is also given in the A. G. Volodin thesis. The above-mentioned works also have references to the findings of skarn and ore xenoliths in the Sarlyk massif granites, and to other data on this subject. In addition, V. A. Vakhrushev's claim to the originality of his data perplexes the geologists familiar with that material.

2. On the basis of the above-mentioned facts, V. A. Vakhrushev concludes that the Sarlyk massif granites are younger than the Sheregesh ores and skarns. The Sarlyk massif is made up chiefly of gray coarse-crystalline, uneven-grained biotite granites. In the contact zone, there are hornblende streaks (schlieren) and reddish light-colored variettes of granite, almost identical to white granites in their structure, and probably having originated in the diffusion of alkalis (potassium) from magma to the contact zone. Both types of granites, and the hornblende streaks, are cut by veins of pegmatoid granites and pegmatite-aplites. The same veins cut the Sheregesh skarns and ores.

A similar relationship between silicic vein rocks and skarn-ore bodies and their parent intrusions occur in many contact iron ore deposits of the Urals and Siberia. Accordingly, the cutting of the Sheregesh skarns and ores by veins of pegmatoid granites and pegmatite-aplites implies only a younger age for the vein intrusion differentiates, and not for the intrusion itself. Nor do the reaction phenomena between vein granites and skarn-ore formations tell anything of the age. Such phenomena would be developed in a mineralization younger than the granites, because they are related to the activity of post-skarn ore and post-vein solutions. For this reason, the author's statement on the absorption of the Sheregesh deposit by the granites is unconvincing and erroneous. Moreover, it confuses field studies, because the barren character of the endocontact zone of the Sarlyk massif has been quite definitely established by geophysical work.

The proof that the Sarlyk massif granites are younger than the Sheregesh skarns and ore is given in our work [4]. Taking into account the new data on the Sheregesh deposit, this proof can be reduced to the following points: 1) apophyses of gray biotite granites of the Sarlyk massif (rather than its vein differentiates) cut the skarn-ore bodies of the deposits and carry xenoliths of skarns and magnetite ores; 2) although the skarns and ores are locally broken up by a dense network of parallel fractures, the granites are massive; the cleavage fractures of xenoliths do not persist beyond the skarns and ores, which suggests a break between the formation of skarn-ore bodies and that of granites; during that break, the skarns and ores underwent schistosity (borehole No. 107); 3) skarn ore bodies and lateral rocks of the deposit are cut by numerous infiltration, symmetrically-zonated polymineral veins of red-brown garnet (almandine-spessartite), thulite, zoisite, columnar epidote, magnetite, sodium-ferrous hornblende, sulfides (including sphalerite), etc. In addition, these minerals form druses filled with calcite and quartz. This mineral complex is superimposed on the already cleaved skarns and ores. The peculiar composition of this mineral assemblage, and its younger age as compared with the skarns and ore deposits, suggest its association with the granites, especially since red-brown garnet grains occur in places in granites of the massif's edge zone where they undoubtedly have come from the skarn-ore formations, in the latter's metamorphism by the granites (borehole No. 191). Identical garnet occurs also in contacts of pegmatoid granite and pegmatite-aplite veins with the skarns, unless it has been obliterated by the subsequent metasomatic reactions; 4) skarns and ores of the deposit have been intensely biotitized, amphibolitized, and pyrrhotitized.

3. V. A. Vakhrushev doubts the contact-metamorphic origin of the biotite, amphibole,

and pyrrhotite, and refers to the unpublished works of V. M. Klyarovskiy and O. G. Kine on the Tel'bes area iron ore deposits, non-metamorphosed by granites. In this connection, K. V. Radugin postulated, as early as 1945, two ages of the Tel'bes magnetite mineralization. The older of the two (Kazskoye) has traces of a contact metamorphism with granites (L. Ye. Baranovskaya, 1956). Moreover, it has been accepted by now that the formation of most granite intrusions took place in many phases (granodiorites-normal granites-leucocratic and alaskite granites), with the assimilation and hybridism diminishing toward the end of the cycles (V. S. Koptev-Dvornikov, 1952). Many silicic intrusives of western Siberia, too, have a multiphase character. As early as 1927, M. A. Usov separated several phases in the history of the formation of the Tel'bes iron ore-bearing intrusion. According to him, the first batches of the intrusive magma had a basic quartz diabase-andesite composition; upon crystallization in contact zone, they formed andesinites, opdalites, quartz monzonites, and augite-diorites. The next phase included adamellites, with alkaline granites emerging still later on. The skarn magnetite mineralization of that region is related to the first phase of the formation of the Tel'bes intrusive, and closely associated with monzonites, diorites, and other hybrid forms. The development of amphibole, biotite, and pyrrhotite in these rocks, skarns, and ores, is undoubtedly related to the effect of later phases of the Tel'bes intrusive. For this reason, for instance, the Temir-Tau deposit contains not only pyrrhotite, biotite, and sodium-ferrous amphibole, but red-brown garnet of almandine-spessartite composition, which is usually not characteristic for skarns. This garnet forms incrustations in adamellite near its contact with skarn ores. We believe, therefore, that all of the above-mentioned minerals in the Tel'bes iron ore area have originated in the same way as in the Sheregesh deposit. The literature on skarns mentions a similar situation in many skarn deposits of central Asia (N. V. Nechelyustov, 1957; Kh. M. Abdullayev, 1955).

In conclusion, I want to thank A. G. Volodin, Chief Geologist of the Gorno-Shor Expedition; Yu. V. Rozhdestvenskiy, Chief of Expedition; and T. V. Tyumentseva, District Geologist, for the information given to me during my visit to the Sheregesh deposit.

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CHRONICLE[1]

THE ANNUAL CONVENTION OF THE GEOLOGICAL SOCIETY OF AMERICA[2]

by

D.S. Korzhinskiy

Annual meetings of the American Geological Society and associated organizations take place in different cities of the U.S.A. In 1958, the Academy of Sciences U.S.S.R. received an official invitation to participate in the annual convention, in Saint Louis. The delegates were corresponding members of the Academy K.A. Vlasov, V.V. Belousov, and the author.

K.A. Vlasov and myself left Moscow by air, November 3 and arrived at Saint Louis the next evening. On November 5, we participated in one of the field trips to a Missouri lead mine. The meetings took three days, November 6-8. V.V. Belousov and myself read our papers. After that, K.A. Vlasov went to see the South Carolina pegmatite deposits, while I left for Los Angeles and then Berkeley to see the petrologic research laboratories at the University of California. On November 17-18, we both visited the Carnegie Institute Geophysical Laboratory and the U.S. G.S. Laboratory, in Washington. Afterwards we visited the New York Museum of Natural History and left New York on the 20th to arrive in Moscow on the 21st.

The Saint Louis Convention; its organization. Annual conventions of the American Geological Society take turns in different cities of the U.S.A. The first convention took place in 1888, making the current 1958 convention the 71st. The convention is held in conjunction with other societies, such as the Paleontological, Mineralogical, Geochemical, Economic Geologists, and the Association of Geology Teachers. Besides the scientific sessions, there are business meetings and reading of annual reports of the societies and their commissions and boards, with the awards of medals by different societies. The presidents-elect of the several societies deliver their "presidential addresses;" there are exhibits by the scientific organizations and publishing houses and the demonstration of new scientific films. These conventions are the main meeting place for geologists working in different branches and in different states of the U.S.A.

This convention was well organized. A detailed program of the Convention had been prepared, with abstracts (250 words) of all papers, a total of about 320. The deadline for the abstracts was July 15. Altogether 282 papers were read.

The papers were grouped into 15 sections. They were read in two daily sessions of three hours each. In most sections, each paper was given ten minutes (with 15 minutes in some sections), with five more minutes for questions and discussion. This schedule was maintained, and the papers were announced according to the program, down to a minute. Opening one of the sections, the chairman requested limiting each remark to "no more than 30 seconds." Withal, there was no special haste and strain, and there was time out for jokes. I have the impression that such a schedule is quite adequate, in most cases, to acquaint the audience with the gist of each paper and to provide opportunity for the most pertinent questions and remarks.

Annual meetings of the several societies took place at a special lunch or dinner, the tickets for which were available to any participant. Here, at a solemn ceremony, the societies' medals were awarded to geologists for their scientific achievements. The recipients were as follows: J. Gilluly, J. Verhoogen, L. Leopold, T. Meddock, M. Buerger, C. Weaver, C. Behre. The awards were accompanied by speeches of presidents or representatives of the awarding societies and and the recipients.

[1] Khronika

[2] Na godichnom sobranii geologicheskogo obshchestva S.Sh.A.

There was a number of annual meetings ("smokers") of alumni of larger universities, "cocktail hours," etc., where old acquaintances were renewed and new ones made. There was a special room where young geologists in search of employment could meet their prospective employers or their representatives.

On exhibition were scientific publications, equipment of different companies, and products and articles by various geological and geophysical research organizations.

Such annual conventions undoubtedly are, on the whole, a happy way of bringing geologists together and to promote the development of geology.

Besides ourselves, there were several foreign geologists; from England, Canada, Japan, and other countries.

Scientific papers at the Saint Louis convention. The papers read at the convention reflect well the general trend of geologic research in the U.S.A., and to that extent my attendance was profitable. My special interest was papers on petrology. A considerable portion of these dealt with the experimental treatment of petrologic problems. Most of the remaining, purely petrologic, papers had to do with the physical and chemical problems of rock formation, on the basis of the study of paragenetic relationships of minerals, with special mineralogic investigations, and thermodynamic calculations. There were only a few papers on the standard petrographic study of outstanding formations or on regional petrography. Of course, such study is being done in the U.S.A., on a large scale, but apparently is not deemed of sufficient interest for scientific papers.

Among the many excellent papers read in Saint Louis, there were none outstanding enough to make scientific landmarks, at least not in petrology. However, many papers advanced well substantiated new physical and chemical premises which, although specific, are important in petrology. Thus, the experiments by O.F. Tuttle demonstrated that calcium, at a pressure of 1000 atmospheres and more, in the presence of water, begins to fuse at temperatures as low as 740°C. This, according to Tuttle, suggests the possibility of an igneous formation of carbonate rocks and the fusing of limestones in the intrusive contacts. According to experiments of C. Burnham and R. Jahns, granites and pegmatites, when subjected to a pressure of 3000 atm, fuse at 665°, i.e., at a temperature lower than believed before; at that pressure, they absorb no more than 5.5% by weight, i.e., less than that obtained by R.V. Goranson.

A number of papers dealt with the experimental study of phase states in water solutions, for feldspars, micas, zeolites, and with the solubility of sulfides, etc. A number of petrologic papers touched on the paragenetic relationship of minerals and on the distribution of both the principal and dispersed elements, for the coexisting minerals. Such was the paper by R. Kretz on garnet, hornblende, and biotite, in Grenville gneisses. J. Rosenfeld, J. Thompson, and E. Zen showed that in the Vermont crystalline schists, muscovite coexists with paragonite. They presented a diagram of the equilibrium ratio for these minerals. Of interest were data on the metamorphism of crystalline schists from San Francisco, with a wide development of jadeite accompanied by lawsonite and glaucophane. B. McKee, A. Regis, and L. Sandom have discovered for the first time, natural carbide of silicon, in salt deposits subjected to volcanic exhalations, with the latter interacting with bitumens and quartz of the underlying shales.

In some papers, petrologic observations and considerations were supplemented by a thermodynamic computation of mineral reactions. C. Thornton and D. McIntyre reported on the start of the work, recounting all chemical analyses of rocks published after 1914. The recount will be done by the system of G.S. Washington and three other American authors, with some improvements, by computing machines. In one minute, the machine will do about 30 recounts, typed on cards and ready for printing.

The convention papers, along with the subsequent acquaintance with some of the scientific research institutions, have demonstrated that not only the experimental petrologic study but the physical and chemical methods and knowledge are generally more and better developed in the U.S.A. than in this country.

There is no need to report here on all of the presented papers, inasmuch as their abstracts will be published in the December issue of the Bulletin of the Geological Society of America. I shall only note the great deal of attention given to the problems of terminology and the reporting on the results of geologic studies. This topic was taken up by a special symposium, "Communications in Geology," with seven papers read. This shows that more attention is paid to terminology and exposition in the U.S.A. than in this country, and that the English language, both scientific and conversational, is being developed much faster than the Russian. An English version of a text is shorter than the Russian one. Obviously, more attention should be paid to the development of Russian scientific language.

Geologic field trips. Several field trips were organized during the convention. K. A. Vlasov and I participated in the trip to one of the southeastern Missouri lead mines. The origin of this deposit is controversial, with much written about it ("Mississippi type deposits"). The mineralization here (galena, sphalerite) is associated with Upper Cambrian "Bonne-Terre" dolomites underlain by porous sandstones. It follows the stratification, except for rare ore veins which cut the sandstones. Galena is especially abundant in layers of black shales whose color is due to fine dispersion of iron disulfide rather than to organic matter. The latter is lacking there, according to new data. The general trend or ore segments toward large faults, along with the coarse grain of most ores, suggests their hydrothermal origin. However, the only positive evidence of endogenetic processes in Missouri has been encountered in ill-defined explosion vents with the formation of apatite alone, presumably endogenetic. These vents are tens of miles from the mines. Only Precambrian granites have been discovered, by drilling, in extrusive rocks. They are transgressively overlain by the Paleozoic ore-bearing sequence. It is of interest that D. White's paper described the similarity in the composition of liquid inclusions of galena and sphalerite of these deposits with brines of oil-bearing formations rather than with magmatic or volcanic waters. These are the inclusions with a predominance of chlorides of sodium and potassium, and with an insignificant amount of other components. The local geologists regard the deposit as hydrothermal. Its epigenetic nature is recognized by everybody.

I also participated in the trip from Los Angeles to the Palm Canyon area, San Jacinto Mountains, 110 km east of Los Angeles and southeast of Palm Springs resort. The party consisted of A. Engel (leader), Professor S. Tilley, H. Yoder, W. Holzer, Mrs. A. Engel, and myself. The objective of the trip was the granitization phenomena. Metamorphic pre-Mesozoic (probably Precambrian) shales and marly schists with quartzites change along the strike to gneisses and migmatites with layers of granites more resistant to granitization. Farther on, there are gneisslike granites and then massive (Mesozoic?) granites which we did not see. The granitization of a sedimentary section, postulated by A. Engel, was indeed very convincing, as it is, by the way, in most other areas of the development of crystalline schists. Nevertheless, C. Tilley argued against the granitization, advancing a theory of a purely metamorphic origin of the gneisses and disputing the gradual transition from schists to granites, by way of gneisses.

The Carnegie Institute Geophysical Laboratory, in Washington. This is the world's best known center of scientific research. Despite this fact, the number of its personnel is very small. For this reason, its organization deserves special study. As shown in the printed report of the Laboratory for 1956-1957, its staff includes only 16 scientific workers and about 16 persons of the technical and service staff, including the instrument men, a stenographer, a librarian, a building superintendent, etc. In addition, there are visiting research workers and fellows.

The laboratory takes up a large, isolated two-story building. The basement houses a spacious work shop where the experimental equipment is built. Each research worker has a separate, excellently equipped laboratory. An amazing fact is the absence of laboratory assistants, with the research workers doing everything by themselves. For instance, the well-known and aging scientist J. Schairer does, all by himself, the painstaking work on the condition diagram. His work calls for testing of hundreds of samples, each one to be fused several times, for homogeneity, and then checked by immersion. J. Schairer demonstrated the entire procedure for us, exhibiting amazing dexterity. To our suggestion that J. Schairer and other scientists perhaps should be given technical assistants, P. Abelson, the laboratory director said that, first of all, he did not have the money; and second, that even with money, "the brain is better than the brawn." In all other American research institutions, too, the laboratory assistants of our type, as a rule, are missing. Generally speaking, rigid economy is exercised on technical personnel. Besides this economic factor, this is probably determined by the English tradition for "do-it-yourself" science.

Members of the laboratory staff have their business travel expenses paid (conventions, field trips, etc.). Yet, they cannot do any consulting work for private companies or any kind of outside work. Their pay is somewhat lower (by about 10 percent) than for a similar qualification in other organizations. The turnover is fairly large, with staff members going into employment with other institutions (universities, U.S.G.S., etc.).

There is no formal scientific board for the Laboratory, with the Director in charge of everything, after a consultation with such staff members as he chooses.

The Laboratory scientists have a strenuous work schedule. Thus, J. Schairer spends all day there and sometimes works in the evening. H. Yoder relates that he used to spend nights in the laboratory, prior to the installation of new thermostats.

The Laboratory's field of activity comprises

the study in crystallochemistry, crystallography, the absolute-age determination, the condition diagrams of rock and ore-forming mineral systems, along with an experimental study of the magma and metamorphism problem and studies in paleobiochemistry. Each man works on several projects, some of which are collective. An annual report is published, setting forth the preliminary results. A seminar is held each week on the progress of work, with visitors from other institutions participating. Now and then, symposia and larger meetings are held ("Petrological Club"). The staff members commonly lecture in various universities and institutions of the U. S. A.

We have visited several laboratories. Inasmuch as the purpose of all research work is readily accessible from the annual report, we confine ourselves to a few specific observations. Our attention was arrested by the new electronic thermostats which maintain the temperature for two weeks, down to one degree centigrade. The O. F. Tuttle dismountable hinged furnaces are very interesting. Gas pressures as high as 3000 atm are transferred by means of capillary tubes as flexible as common wire, made of stainless steel, diameter 1.6 mm, with the inside diameter of 0.4 mm. Of interest are G. Eigster's experiments with wetted powders in thin metal capsules, isolated by buffer mixtures (such as hematite and magnetite, to maintain a constant oxygen pressure). At high temperatures and pressure, the powder is metamorphosed, with a development of well-formed crystals (such as biotite, orthoclase). In the presence of steam, these crystals are not baked together and are readily isolated for convenient study with the microscope and by immersion.

Our visit was made to coincide with a discussion, held in the Laboratory's small auditorium, of the thermodynamic analysis of ion reactions and of the classification of components by applying the phase rule to natural mineral parageneses (communications of R. Garrels, J. Thompson, and my own).

University of California at Los Angeles and Berkeley. The oldest part of the University is located in Berkeley, near San Francisco, with other branches in various parts of California. The earliest branch, in Los Angeles, has since grown into an independent school (University of California, Los Angeles). In buildings and in enrollment (about 15,000), it now exceeds the Berkeley component.

The Los Angeles Geology Department of the University is housed in a large modern building on the campus. Its present chairman is a comparatively young professor, J. Crowell. A departmental chairmanship is regarded here as an elective post and a chore, with the professors alternating on the job. Of the twelve professors of the department, G. Tunnel, J. Rosenfeld, and J. Murdoch are working in geochemistry, mineralogy, and petrology. J. Tunnel works on the mineralogy of ore deposits (currently, on mercury deposits of western states), crystallography, and chemical thermodynamics. He also experiments on the equilibrium of ore minerals and on their solubility. He participated in the XVII session of the International Geological Congress, Moscow, 1937; he reads Russian and holds correspondence with some Soviet scientists. He recommended the new "tetrafluorethane" plastic for experiments at 1 to 250°C and pressures as high as 1000 bars. The shelves of his spacious cabinet store a large collection from various ore deposits he has visited.

The young professor, J. Rosenfeld, is busy with the problems of metamorphism. In the summer, he carries on a systematic study of the New England metamorphics; in the winter, besides teaching and processing the summer material, he works on the theory of metamorphism. Like the other professors, he has a spacious working room but no assistants. He showed me through a large laboratory of the Geology Department, which was without permanent staff, and with the work done by the professors, graduates, and students, according to their needs. Here, as in other research organizations of the U. S. A., there is an abundance of equipment and space, with a very rigid economy in personnel. J. Rosenfeld has a dictograph in his office, into which he dictates his reports and the simpler scientific works. In the secretary's office, the record is transcribed, corrected by the author and typed.

The aging professor J. Murdoch, about to retire, is busy on purely mineralogic study. He is regarded as an outstanding expert on rare minerals from limestone contacts of the Crestmore and Riverside near-surface intrusions.

The University maintains a geophysical research institute staffed by Professors D. Griggs and K. Kennedy. D. Griggs experiments on the deformation of marbles and other rocks, with the petrographic portion of the work done by Prof. F. Turner, at Berkeley. Professor K. Kennedy was not present, but his collaborators let me see the equipment. They study the transmutation of minerals at pressures of 100,000 bars and temperatures as high as 1500°C. At room temperature, the pressure rises to 200,000 bars. At the last stages of compression, the piston squeezed out metal bismuth.

At Berkeley, the Geology Department is

housed in a handsome, but outdated and inadequate, brick building. The lack of space here prevents the initiation of experimental study, according to Professor F. Turner, Chairman of the Department. F. Turner, a New Zealander by birth, emigrated to the U.S.A. in the forties, the same as J. Verhoogen from Belgium, H. Ramberg from Norway, and many others. The development of geology in the U.S.A., especially theoretic geology, is the result to a considerable extent of immigrant scientists. F. Turner is an outstanding expert in petrology, especially of metamorphic rocks. His "Evolution of Metamorphic Rocks" has been translated into Russian. In the excellent text, "Igneous and Metamorphic Petrology," by F. Turner and J. Verhoogen, the chapters on metamorphic and extrusive rocks were contributed by the first author, whereas the second author considered the physical and chemical problems. At the present time, F. Turner, in collaboration with D. Griggs, is studying rock deformations, while working on the second, enlarged, edition of his and J. Verhoogen's book.

Professor J. Verhoogen had been trained as a geologist. His first task was a study of the erupting volcano Nyamlajira, in Africa. According to his own words, that task convinced him that geology was "too complicated for him," and he switched to geophysics. He is now working on the thermodynamic of petrology.

Adjacent to the Geology Department, there stands a large building of the College of Engineering where I was shown the spacious laboratories of the Department of Mineral Technology. The laboratories are very well equipped for studies in thermography, calorimetry of alloys, phase equilibria in ceramic and metal systems, flotation, mechanical enrichment, etc. Working here are Professors J. Pask, H.E. Hawkes, and P. Witherspoon. H.E. Hawkes is editing a translation from the Russian of I.I. Ginzburg's book on geochemical methods of prospecting for ore deposits and the proceedings of the conference on that subject. He is enthusiastic about the work of the Soviet geologists in that field.

Both in Los Angeles and in Berkeley, I repeated for the benefit of the students and teachers my Saint Louis paper, "The Advanced Wave of Acid Components In a Hydrothermal Acid-Alkaline Differentiation." It turned out that the American geologists had no idea of the permeability (filtration) effect, and were very much interested. Most of the questions had to do with the experimental aspect of the permeability and acid-permeability effect, rather than with the geologic characteristics of the process, which was the main subject of the paper. Afterwards, a discussion of some thermodynamic problems connected with the mineral paragenesis analysis took place in a smaller circle of professors.

Meeting with the staff of the California Research Corporation and the California Institute of Technology. Because of circumstances beyond my control, I was unable to visit either of these institutions, the first located at La Habra, the second at Pasadena, both suburbs of Los Angeles. However, I met with the members of their staff, at a reception kindly arranged by Mr. and Mrs. Holser, at their home.

The California Research Corporation was organized and is financed by the Standard Oil Company of California. The geologists and geochemists, engaged by the corporation, carry on research in fields related to the origin of oil. In addition, they give some of their time -- about 10 to 20 percent, I was told -- to consultations with the company geologists, in their respective fields. Director of the Corporation is A. Hillebrandt (physicist, son of the well-known chemist). Among the projects under way are: the distribution of elements in sedimentary rocks (J. Green, Smolley); isotopes of oxygen, hydrogen, and sulfur in sediments and crudes (Silverman, H.G. Thode); the study of evaporites (W. Holser); paramagnetic resonance in mineral systems (R. Rex); and sedimentology (W.V. Plumley). J. Green has prepared for publication his "Geochemical Table of Elements, for 1958," with an explanatory text. He presented the Soviet scientists with several manuscript copies of this useful work, which ought to be translated into Russian.

Present at the reception were professors of the California Institute of Technology, A. Engel, C. Tilley and Doctor H. Yoder. C. Chilley (Cambridge University, England) and H. Yoder (Geophysical Laboratory, Washington, D.C.) were visiting professors at the institute. They were supposed to give a short joint course (about 16 hours) for one semester, on physical and chemical petrology. This practice is very common in the American universities. A visiting professor keeps his original salary from his school and the host school pays the extra expenses. This honorary invitation gives the professor a chance to prepare a special course and to get acquainted with a new environment.

The Geological Survey, Washington, D.C. While in Washington, K.A. Vlasov and I visited the division of geochemistry and petrology, U.S.G.S. The present Chief is W.T. Pecora, known for his work in the petrology of alkali rocks, especially of carbonates. He took the place of E. Ingerson who left to become a professor at the University of Texas, at Austin. This division unites the

Survey laboratories, with the experimental petrologic-mineralogic studies isolated into a "solid state group," under E. Roedder. There are several laboratories for the study of the condition diagrams of rock-forming mineral systems, specifically of alkali amphiboles. (D. Stewart, B. Skinner). As in all other similar American laboratories, the equipment is standard, like that in the Carnegie Geophysical Laboratory. For lack of space, those laboratories which work on the "Mineralization Medium" project are temporarily located at the other end of the city, in one of the Naval Arsenal buildings. Here they study the solubility of iron oxides in water, fluid inclusions in minerals, etc. (E. Roedder, G. Morey, P. Barton, P. Toulmin). Unlike the Geophysical Laboratory, some of the laboratories here have assistants. According to W.T. Pecora, there is one assistant for each research worker, on the average. In addition, there are graduate students working there.

The U.S.G.S. library has a vast store of books, with the Russian geologic literature, both pre-Revolutionary and Soviet fairly well represented. There is a periodicals file, and a file of books by authors. There is no subject file, nor one for the papers' authors. Again, this is because of the same rigid economy in technical personnel, who are engaged only for most urgent needs. Although the library contains reprints of some individual papers, they are hard to find. The geologists told us that whenever they want a reprint, they first try a leading expert in that field, who might have an author's copy. Only if that fails, do they come to the library. Such mutual assistance with reprints apparently is very common among the American geologists. Thus J. Thompson told me that a reprint of one of my papers, which I had sent to E. Larsen, was loaned by him to M. Billings who loaned it to J. Thompson who became interested in that field.

Visiting the geological divisions of museums. While visiting the National Museum, in Washington, and the American Museum of Natural History, New York, we especially wanted to see the specimen exhibits from different localities. It turned out, however, that these museums, with all their halls of mineral collections, including the resplendent exhibits of precious stones and building stones, also large paleontologic collections, did not have exhibits arranged by ore sites and by petrology. In this respect, museums in the U.S.S.R. and in a number of other countries are much more interesting. However, stored in conventional cabinets in museums' storehouses, there are collections of small specimens, by ore sites.

Very effective are the artistic diaramas in zoology, botany, ethnography, soil profiles, etc., at the American Museum of Natural History.

Bryan Mason is Director of the Mineralogical Department of that museum. He is the author of "Principles of Geochemistry." In his position of Director, he is completely free to choose the field of his study. Thus, for the last few years, he has been carrying on a petrologic study in Australia. This study is financed by the Museum, although the latter does not have a petrology department.

I have noticed that, in all of the visited institutions, the cabinets for rock specimens are standard, of the same size; and made of sheet steel instead of wood as we have them.

The interest in Russian geologic literature and the Russian language. There is a widespread change in the regard for Soviet science in the U.S.A. Many geologists are studying the Russian language and are beginning to read, with a dictionary, short articles in Soviet geological magazines (J. Tunnel, E. Ingerson, H. Yoder, and others), and a number of geology students are beginning to study the Russian language and help their older colleagues follow the Soviet literature.

Translations and publications of recent Russian literature are underway. This is true for the English publication of the geologic and geochemical series of Doklady of the Academy of Sciences, U.S.S.R., and magazine "Geochemistry." The Geochemical Society of America is financing the English publication of many Soviet books, with the translation and publication done, for the time being, by private organizations, under the Society's supervision. The leader and editor for this project is Professor E. Ingerson. Such work has been most advanced in the privately owned, Consultants' Bureau which has prepared for publication A.P. Vinogradov's "Geochemistry of Rare and Dispersed Elements in Soils," and D.S. Korzhinskiy's "Physical and Chemical Principles of Mineral Parageneses Analysis." Since 1958, this organization has translated some 50,000 pages of Russian text, in different fields of science. The circulation of these publications is 1000 to 1500 copies. In 1959, a new Translation Center will begin activity, under the direction of R. Fairbridge, Professor at Columbia University (New York). This Center is a part of the American Geological Institute, a nationwide organization. Already translated are V.V. Belousov's "Main Problems of Geotectonics" and D.V. Nalivkin's "Theory of Facies." Another group has prepared for publication I.I. Ginzburg's "An Experiment In The Theoretic Basis of Geo-Chemical Methods of Prospecting." Some private enterprises are about to launch the business of publishing Soviet magazines and books.

The American geologists displayed the friendliest regard for us, the Soviet geologists.

/e were touched by the attention and con- ideration given to us. For instance, noted cientists would meet us at the airport, with ieir cars, and show us about the town. To y over a new country is a delight to a eologist and geographer. I shall pause here or a single observation. As clearly seen rom an airplane, contour ploughing is used verywhere in the U.S.A., in hilly terrain. he plough lines strictly follow the contours, iving the effect of a topographic map. At rst glance, these lines can be mistaken for horizontal rock outcrops. On the eastern Appalachian slopes, where I first saw them, on my way from New Orleans to New York (in 1956), these lines were so sharp that they give the impression of terraced slopes. Now I have seen them on the western slopes of the Rockies. The contour ploughing is very important in reducing soil erosion and water runoff.

D.S. Korzhinskiy

FIFTH ANNIVERSARY OF THE DEATH OF ACADEMICIAN D.S. BELYANKIN[3]

The December 19, 1959 session of the etrographic Circle at the Institute of Geology f Ore Deposits, Petrography, Mineralogy, nd Geochemistry, Academy of Sciences, .S.S.R., was dedicated to the memory of cademician Dmitriy Stepanovich Belyankin, 1 connection with the 5th anniversary of his assing away.

After an introductory word by the Corresponding Member of the Academy, G.D. Afanas'yev, the following speakers — students and followers of Dmitriy Stepanovich — were heard:

1. V.P. Petrov, on "Life and Activity of D.S. Belyankin."

2. V.V. Lapin, on "D.S. Belyankin as the Creator of Technical Petrography."

3. G.D. Afanas'yev, on "Cenozoic Igneous Activity in the Caucasus."

4. A.S. Marfunin, on "The Geology of Phase Mutation In the Solid State."

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[3]5-ya godovshchina so dnya konchiny akademika .S. Belyankina.

TO THE AUTHORS[1]

1. Izvestiya of the Academy of Sciences, U.S.S.R. publishes papers in the geologic sciences: general and historic geology, tectonics, stratigraphy, petrography, mineralogy, geochemistry, lithology, the theory of ore and other minerals, and in the history of these disciplines.

The section, "Reviews and Discussions," contains discursive and critical articles on various geologic problems and reviews of published works.

The length of the papers should not be more than 25 to 30 typewritten pages.

2. Priority is given to papers on general theoretical problems of geology and to those read in the Division's meetings; next to geologic works performed in the Academy's Institutes.

The submitted material should be accompanied by a written authorization of the organization which financed the work, and by a proper certification as to its eligibility for publication in the Izvestiya, Geologic Series.

3. The submitted papers should be finally corrected, dated, and signed by the authors. No subsequent changes will be permitted.

The title of the paper should be followed by an abstract presenting the author's thesis supported by the material of the text.

4. The galleys are presented to the authors for control only. Stylistic corrections, additions, and deletions, or any changes in the text will not be accepted.

5. Only those manuscripts are accepted which come up to publication and printing standards. They should be clearly typed on one side of white paper, impermeable to ink, double spaced. Handwritten and carbon manuscripts will not be accepted.

6. The names of foreign authors, in the text, should be given in Russian transliteration.

7. Abbreviations, except for the common ones (such as 1 m, 2 kg, etc.) are unacceptable.

8. Latin names of fauna, formulas, and all foreign texts, should be typed or transcribed clearly and unmistakably. To avoid mistakes, a clean-cut distinction should be made between the upper and lower case letters, such as K, O, S, V, M, etc. by marking them with two lines below, for capital letters, and with two lines above for the lower case. All indices, exponents, and Greek letters should be carefully outlined, with corresponding marginal notations.

9. All units of measure should conform to the standard symbols (if there are such), according to the All-Union Standard V.K.S.

10. Numerical tables, such as of chemical, mineral, and other analyses should be individually certified by the author, with indication of the method of obtaining the data.

11. The literature cited is to be given, not in footnotes, but in a general list, at the end of the paper. The authors are listed in alphabetic order, the Russian sources first, and are so numbered. The reference in the text is marked by the corresponding number in parentheses.

12. The literature is cited in the following way: for books -- the name of the author, his initials, a full and precise title, the number of the volume, part, issue, the publication name and year; for magazines -- the author's name and initials; the title, the magazine name, number, and year; if necessary, the volume and issue number.

13. Illustration with maps, cross sections, and photomicrographs is admissible only when they complement the text and are indispensable for the author's thesis. Any graphic

[1]Vnimaniyu avtorov.

TO THE AUTHORS

material which has no direct bearing on the subject of the paper will not be accepted.

14. The illustrations should be appended to the manuscript, with all items numbered and accompanied by a list of legends. A minimum of numerical and letter symbols, corresponding to the text, should be used in the illustrations. Their explanations should be given in the legend.

15. Places for the figures and tables should be indicated in the manuscript.

16. The reverse of each illustration should carry its number, the author's name, and the title.

17. The manuscript pages should be numbered and if possible, bound in a folder. The illustrations and legends should be placed in a separate envelope.

The author's name, his address and telephone number should be given at the end of the manuscript, or on the folder.

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